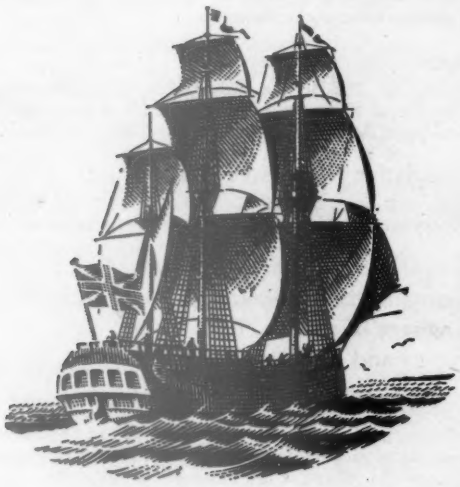
ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind



VOLUME IV · 1945

Endeavour

VOLUME IV 1945

LIST OF ARTICLES alphabetically arranged under authors

Author	*Article*	*Page*
BARTLETT, F. C.	Some growing-points in experimental psychology	43
	F. C. BARTLETT, C.B.E., M.A. (London and Cambridge), Hon. D.Phil. (Athens), F.R.S., is Professor of Experimental Psychology in the University of Cambridge and Director of the Psychological Laboratory. He edits the *British Journal of Psychology*, and is a member of the Medical Research Council.	
BOWEN, E. J.	Particles, waves, and chemical formulae	75
	E. J. BOWEN, M.A., F.R.S., is University Demonstrator in Chemistry at Oxford. His chief interests in research have been in the fields of photo-chemistry and fluorescence.	
CARTER, G. S.	The flight of flying-fishes	136
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CAVE, C. J. P.	Clouds and cloudscapes	58
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DAVIES, C. W.	Dissociation in salt solutions	114
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EDITORIAL	Chemical control of pests, The	121
	Islam and science: retrospect and prospect	1
	Language of science, The	41
	Science and reconstruction	81
FERGUSON, A.	Dramatic moments in the history of science in Britain	17
	ALLAN FERGUSON, M.A., D.Sc., is Assistant Professor of Physics at Queen Mary College, University of London. He is one of the general secretaries of the British Association for the Advancement of Science, past president of the Physical Society, and one of the editors of the *Philosophical Magazine*.	
GARRETT, S. D.	The root-infecting fungi	104
	S. D. GARRETT, M.A., D.I.C., is mycologist at Rothamsted Experimental Station, and was formerly plant pathologist at the Waite Agricultural Research Institute, University of Adelaide, South Australia.	
HADDOW, A., *and* RUDALL, K. M.	Artificial coat coloration and the growth of hair	141
	ALEXANDER HADDOW, M.D., D.Sc., Ph.D., was Lecturer in Bacteriology at the University of Edinburgh, and is now on the research staff of the Royal Cancer Hospital, London. His main interest is in carcinogenic compounds.	
JONES, E. TAYLOR	Æolian tones	100
	E. TAYLOR JONES, D.Sc. (London), Hon. D.Sc. (Wales), F.Inst.P., F.R.S.E., is Emeritus Professor of Natural Philosophy in the University of Glasgow. His physical research has included work on electrical oscillations, the induction coil, and a quantum theory of electrostatic and magnetic energy.	
JONES, SIR HAROLD SPENCER	Celestial spectra	35
	Measurement of time	123
	SIR HAROLD SPENCER JONES, M.A., Sc.D., B.Sc., F.R.A.S., F.R.S., has held the position of Astronomer Royal since 1933. He is a past president of the Royal Astronomical Society and of the British Astronomical Association, and was vice-president of the International Astronomical Union from 1935 to 1938.	

505 En23 v.4, 1945

LIST OF ARTICLES *(continued)*

Author	*Article*	*Page*
MCKIE, D.	John Harris and his *Lexicon Technicum*	53

D. MCKIE, Ph.D., D.Sc., is Lecturer in the Department of the History of Science in the University of London, and is one of the founders and editors of the *Annals of Science*.

NEWTON, L.	Agar-agar and its supply	69

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PALMER, W. G.	A modern interpretation of the doctrine of valency	108

W. G. PALMER, M.A., Sc.D. (Cantab.), D.Sc., is University Lecturer in Chemistry at Cambridge, and is a Gold Medallist of University College, London.

RAWLINS, IAN	Note on museums	52
READ, J.	Teniers' alchemists	94

JOHN READ, M.A., Sc.D. (Cantab.), Ph.D. (Zürich), F.R.S., is Professor of Chemistry and Director of the Chemistry Research Laboratory in the University of St. Andrews.

RICHARDSON, E. G.	Rheology: the dynamics of real fluids	64

E. G. RICHARDSON, B.A., Ph.D., D.Sc., is Senior Lecturer in Physics at King's College, Newcastle-upon-Tyne (University of Durham). He has specialized in the physics of sound.

RIDEAL, E. K.	Surface chemistry in relation to biology	83

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RUDALL, K. M., *see* HADDOW, A.

K. M. RUDALL, M.Sc., Ph.D., has carried out research on the structural interrelationships of biological macromolecules, and has developed the technique of electron microscopy as applied to fibrous proteins and tissues.

SLADE, R. E.	Specific poisons	148

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SMITH, K. M.	Plant viruses	22

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THOMPSON, H. W.	Recent applications of chemical spectroscopy	154

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TURNER, W. E. S.	Modern developments in glasses for technical purposes	3

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TYNDALL, A. M.	Recent work on gaseous ions	29

A. M. TYNDALL, D.Sc. (London and Bristol), F.R.S., is Henry Overton Wills Professor of Physics in the University of Bristol and Director of the Henry Herbert Wills Physical Laboratory.

WHEELER, T. S.	Sir Robert John Kane	91

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WOOD, A.	History of the Cavendish Laboratory, Cambridge	131

ALEXANDER WOOD, M.A. (Cantab.), D.Sc. (Glasgow), is University Lecturer in Experimental Physics at Cambridge. His physical research has been devoted mainly to the study of sound.

SUBJECT INDEX

page

ÆOLIAN tones, E. TAYLOR JONES 100
AGAR-AGAR and its supply, L. NEWTON 69
ARTIFICIAL coat coloration and the growth of hair, A. HADDOW *and* K. M. RUDALL .. 141
ATOMIC energy 130
CAVENDISH Laboratory, Cambridge, History of the, A. WOOD 131
CELESTIAL spectra, SIR HAROLD SPENCER JONES 35
CHEMICAL control of pests, The, EDITORIAL 121
CHEMICAL spectroscopy, Recent applications of, H. W. THOMPSON 154
CLOUDS and cloudscapes, G. J. P. CAVE 58
DISSOCIATION in salt solutions, C. W. DAVIES 114
DRAMATIC moments in the history of science in Britain, A. FERGUSON 17
EXPERIMENTAL psychology, Some growing-points in, F. C. BARTLETT 43
FLIGHT of flying-fishes, The, G. S. CARTER 136
GASEOUS ions, Recent work on, A. M. TYNDALL 29
GERARD, John—herbalist 90
GLASSES for technical purposes, Modern developments in, W. E. S. TURNER 3
HARRIS, John, and his *Lexicon Technicum*, D. MCKIE 53
ISLAM and science; retrospect and prospect, EDITORIAL 1
KANE, Sir Robert John, T. S. WHEELER 91
LANGUAGE of science, The, EDITORIAL 41
MEASUREMENT of time, The, SIR HAROLD SPENCER JONES 123
MUSEUMS, A note on, IAN RAWLINS 52
PARTICLES, waves, and chemical formulae, E. J. BOWEN 75
PLANT viruses, K. M. SMITH 22
POISONS, Specific, R. E. SLADE 148

REVIEWS:

page

Algae, The Structure and Reproduction of the, Vol. II, F. E. FRITSCH .. 160
Art and Scientific Thought, M. JOHNSON 39
Comparative Anatomy, A History of, from Aristotle to the Eighteenth Century, F. J. COLE 39
Determination of Particle Size in Sub-sieve Range, B.C.O.R.A. and B.C.U.R.A... 38
Diseases, Polyglot Glossary of Communicable, YVES BIRAUD 39
Famous American Men of Science, J. G. CROWTHER 40
Flowers in Britain, L. J. F. BRIMBLE .. 80
From Atoms to Stars, M. DAVIDSON .. 80
Hydrocarbon Compounds, Encyclopedia of, Vol. I, J. E. FARADAY 120
Metallurgical Analysis by Means of the Spekker Photo-electrical Absorptiometer, F. W. HAYWOOD *and* A. A. R. WOOD 120

REVIEWS:

page

Materials of To-morrow, PAUL I. SMITH 160
Polyglot Glossary of Communicable Diseases, YVES BIRAUD 39
Plastics for Production, PAUL I. SMITH 40
Problems in the Utilization of Small Coals, B.C.U.R.A. 120
Royal Society, The, 1660–1940, SIR HENRY LYONS 80
Science at Your Service, JULIAN HUXLEY, *et al.*... 160
Seashore Life and Pattern, T. A. STEPHENSON 40
Stars, From Atoms to, M. DAVIDSON .. 80
Structure and Reproduction of the Algae, The, Vol. II, F. E. FRITSCH.. .. 160
Time, Knowledge and the Nebulae, M. JOHNSON 160
Valency: Classical and Modern, W. G. PALMER 38

RHEOLOGY: the dynamics of real fluids, E. G. RICHARDSON 64
ROOT-INFECTING fungi, The, S. D. GARRETT 104
SCIENCE and reconstruction, EDITORIAL 81
SURFACE CHEMISTRY in relation to biology, E. K. RIDEAL 83
TENIERS' alchemists, J. READ 94
VALENCY, A modern interpretation of the doctrine of, W. G. PALMER 108

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Islam and science: retrospect and prospect

His Majesty the King recently paid a visit to the Islamic cultural centre in London, and showed deep interest in the plans for a central mosque which is to be built there, after the war, on a site presented by the British Government. This gracious royal gesture will arouse general satisfaction, and will be particularly welcomed by men of science mindful of the fact that, a thousand years ago, the flame of science burned bright in Islam, and in Islam alone. With the heartening prospect of approaching peace, we may hope that Muslim scientific genius, long dormant, may wake again with all its former energy and vision.

This hope is inspired by a conviction that the several peoples of the world have each their own contribution to make to the advancement of knowledge. During the last three or four centuries, the occidental mould of thought has effected remarkable progress in science; but scientific progress is, at basis, dependent on the fertility of the human imagination. In the words of Kekulé (quoted by Professor Allan Ferguson in his article in our present issue), 'Let us learn to dream, gentlemen,' for that is how theories, great or little, satisfactory or unsatisfactory, are born. We know sufficient now of the rigorous discipline by which imaginings have to be tested, but no one could maintain that the flow of ideas is at present as copious as is desirable. It is in this direction that a scientific renaissance in Islam might have results of the first magnitude, and we trust that the Government's support of the Islamic centre in London is but a symbol of a settled, wider policy.

Forecast of a possible future must be made from a survey of the past. It is therefore appropriate for us to review some of the more important work carried out by Muslim scientists in the heyday of Islam. The years immediately succeeding a widespread religious war might not be expected to favour the quiet assimilation, dissemination, and expansion of learning; yet this unlikely phenomenon was a characteristic feature of early Islam. Many of the Caliphs, such as Harun al-Rashid, showed praiseworthy tolerance to Christian, Jewish, and other non-Muslim scholars; they endowed universities, observatories, and hospitals; they sought manuscripts of Greek treatises for translation and study; and in every way possible they exerted themselves to foster the growth of knowledge.

Such an enlightened policy quickly began to bear fruit. This is not the place in which to make more than a passing reference to the Muslim invention of algebra, extension of trigonometry, and introduction of the Indian numerical signs (with the immensely important addition of a zero sign): but mathematical progress of this calibre was paralleled by progress in astronomy, chemistry, physics, and pharmacology. Al-Battani, for instance, who died in 929 A.D., accurately determined the angle of the ecliptic, the length of the tropic year, and the mean motion of the sun; he proved the possibility of annular eclipses; he recalculated the value of the precession of the equinoxes; and his careful observations of lunar and solar eclipses were reliable enough to be used, as recently as 1749, by the English astronomer Dunthorne in calculating the secular acceleration of the mean motion of the moon.

In Muslim physics the leading figure was Ibn al-Haitam, known to the West as Al-Hazen (965–1038/9). A man of outstanding genius, he opposed the idea, held by most of the ancient philosophers, that the eye transmits rays to the object of vision, and maintained on the contrary that the cause of vision proceeds from the object seen. He discovered one of the laws of the reflection of light, namely that the angle of incidence and the angle of reflection lie in the same plane. He studied

spherical and parabolic mirrors, and one of the problems connected with them that he attempted to solve is still known by his name: 'Given the position of a luminous point and of the eye, to find the point on a spherical, cylindrical, or conical mirror at which the reflection takes place.' Al-Hazen treated of the rainbow, the halo, and the height of the atmosphere, and was the first physicist to describe the human eye in detail. His study of the burning-sphere 'exhibits a profound and accurate conception of the nature of focusing, magnifying, and inversion of the image, and of the formation of rings and colours by experiments.' In the first recorded use of the camera obscura, he observed the semi-lunar shape of the image of the sun during eclipses. Such a catalogue of achievements—and it is not exhaustive—gives Al-Hazen a high place among men of science of any period.

Al-Biruni (973–1048?) is remembered for his experimental skill in determining specific gravities by the 'Eureka can' method. The principle was that of Archimedes, but Al-Biruni made his determinations with a precision that evokes admiration: his figures for the specific gravities of gold (19·05), mercury (13·74), copper (8·83), iron (7·74), tin (7·15), and lead (11·29), are astonishingly close to the modern values. Al-Khazini, who lived a century later, carried accuracy to even greater lengths, and showed that both water at the freezing-point and hot water were of smaller density than water at an intermediate temperature. He further observed that the buoyancy of the air must affect the value of the weight of an object weighed in it. From such facts and figures, his claim to have constructed a balance accurate to 0·06 gm. on a load of 2·2 kg. may well be admitted. It is, indeed, substantiated by other available evidence, from which the sensitiveness of a scientific balance of the time might be judged to reach, on occasion, the remarkable limit of a milligram or so.

The debt of chemistry to Islam is known and acknowledged. The first great chemist in history was Geber (Jabir ibn Hayyan), very many of whose writings are still extant. Little—if anything—is certain about the details of his life, and even the century in which he flourished is a subject of debate. The important fact, however, is that he clearly recognized, and emphatically stated, the indispensability of experiment in chemistry; and though he himself not seldom built mountains of speculation on mole-hills of facts, his books contain plainly recorded descriptions of experiments which show him to have been a fertile worker and a keen observer. On the theoretical side, he elaborated the sulphur-mercury conception of the constitution of metals—the earliest chemical theory properly so called, and one which persisted through the centuries until, in its latest metamorphosis, as the phlogiston theory, it was finally destroyed by the rapier of Lavoisier's scientific insight.

Second only to Geber among the chemists of Islam was Rhazes (Ibn Zakariyya al-Razi), who has been described as the most noteworthy intellectual follower of the Greek philosophers of the seventh to fourth centuries B.C. that mankind produced for 1900 years after the death of Aristotle. His chemical writings evince a passion for objective truth, a rejection of magical and astrological practices, and a firm reliance upon such facts as could be proved by experiment and test. Not the least of his services to chemistry was his systematic classification of chemical substances, which he accompanied with a lucid description of such of their salient properties as were known at that time. From his chemical stature he might appropriately be called the Persian Boyle.

In applied chemistry—that is to say such technical operations as concern the chemist in metallurgy, dyeing, pharmacology, and the like—discoveries must have been very numerous, for the mass of information accumulated was considerable. It seems probable that sulphuric and nitric acids were first prepared by Muslim chemists, and by the thirteenth century cupellation, the 'parting' of gold and silver, the extraction of silver by amalgamation with mercury, and the quantitative analysis of gold-silver alloys, were all being carried out as routine operations at the Cairo Mint.

Geography, botany, zoology, mineralogy, and meteorology were also served by talented disciples.

(*Continued on page* 34)

Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.R.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

Modern developments in glasses for technical purposes

W. E. S. TURNER

Glass-making is an art of prehistoric origin, and like many such arts it remained in a more or less static condition until the science of chemistry reached maturity. With more precise chemical and physical information, progress in the glass industry became possible. During the last 25 years there has been a great increase in our fundamental knowledge of glass technology. Professor Turner describes some modern achievements in this field.

INTRODUCTION

Transparency is the prime quality of glass, and it is due to this quality that it not only finds use as lenses and prisms in microscopes, telescopes, cameras, and a host of other forms of scientific apparatus; as windows; and as containers for the most diverse of substances for domestic, industrial, and scientific purposes; but is being increasingly used in the electrical industries and in large scale industrial equipment. The desire to be able to see beyond the boundary walls has led to forecasts that glass will find application even in machinery, both in outer casings and in moving parts, and, indeed, a beginning has been made in this field.

In order, however, to be of value as a material of construction, a substance needs to be durable and to be mechanically strong. It must resist the action of the weather, and if, simultaneously, it resists corrosion by a wide variety of chemical substances, so much the greater is its adaptability. It must withstand such rapid changes of temperature as the conditions of service are likely to impose; it must be capable of load-bearing and be sufficiently resistant to impact. So the themes round which this article is written are concerned with the enhancement of those properties of glass, namely, its chemical and thermal durability and its mechanical strength, on which its widespread use must depend.

THE CHEMICAL AND THERMAL ENDURANCE OF GLASS

These two subjects can appropriately be discussed together, for it is now well known that, in general, the constituents which enhance the resistance of glass to weathering and to chemical reagents also raise the thermal endurance. Such constituents are silica, alumina, and (within certain limits) boric oxide.

Fused silica, transparent or opaque, stands first in order among glasses in respect of both properties. Vessels for both laboratory and large scale manufacturing purposes have long been made from it and used under exacting conditions, such as in acid distillation plant exposed to the open air. The chemical and heat resistant glasses of complex composition are now also being used on the large scale. Of the five varieties now made in Britain, three have high silica content (> 80 per cent.) and moderately high (*ca.* 12 per cent.) boric oxide content, with 3–4 per cent. of alumina and 3–4 per cent. sodium oxide. They offer very high resistance to water, liquid and vapour, to acids, and to neutral and acidic solutions of salts. They do not resist alkaline solutions so well as do other types in which the total silica and boric oxide content is below 85 per cent. and the proportion of alumina and basic oxides correspondingly higher.

The most recent and, in several ways, the most interesting of the chemical and heat resistant glasses, 'Vycor,' is itself based on the corrosion product of a parent glass; and the process followed in its manufacture avoids the use of the very high temperature, which, from its composition, one would expect to employ in melting it direct from its constituents.

When the silica in a soda-potash-lime-silica glass, such as constituted the older type Kavalier chemical apparatus glass, is progressively replaced by boric oxide, the chemical resistance is not only not improved but, after the boric oxide has reached 10 per cent., is steadily reduced until, when it exceeds 30 per cent., all the constituents except silica can be extracted by hydrochloric acid, leaving a skeleton of silica in the shape of the original article (Turner and Winks, 1926). Some years later a worker at the Corning Glass

Works (U.S.A.) made the surprising observation that the skeletons obtained by the acid extraction of alkali-boric oxide-silica glasses did not break up when heated strongly but shrank steadily to yield a transparent glass approaching in properties those of transparent fused silica. Hence the basis of the process for making 'Vycor' glass. The desired article is first made in the form of alkali-boric oxide-silica glass. With certain compositions (B_2O_3 about 20 per cent.) it is necessary to apply heat treatment for some hours at 500°–650° C, when the glass separates into two phases, one rich in silica and insoluble in acid, the other rich in boric oxide and readily extracted by acid. The article is accordingly extracted by acid in a hot bath, the time needed being dependent on the thickness of the vessel. After washing for some hours with running water, the skeleton is heated at a temperature of 900°–1,000° C. During this stage it undergoes overall shrinkage, between 20 and 30 per cent. in each dimension, dependent on the amount of the oxides retained other than silica. The commercial product generally has a composition of 96·5 per cent. SiO_2 and 3 per cent. B_2O_3 (Table I).

The thermal endurance of a glass is generally defined as the difference of temperature needed to bring about cracking when a test piece of standard dimensions is suddenly cooled in water at 20° C. H. Schönborn (1936) showed that its value varies inversely with the linear thermal expansion coefficient. Thus, when tested in the form of rods 12 cm. × 0·5 cm., the thermal endurance values for four different glasses were 280°, 170°, 120° and 100° C, respectively, the corresponding linear thermal expansion coefficients being 367, 550, 830 and 1,000 × 10^{-8}. Accordingly, the glasses of lowest thermal expansion coefficients are those of the highest thermal endurance.

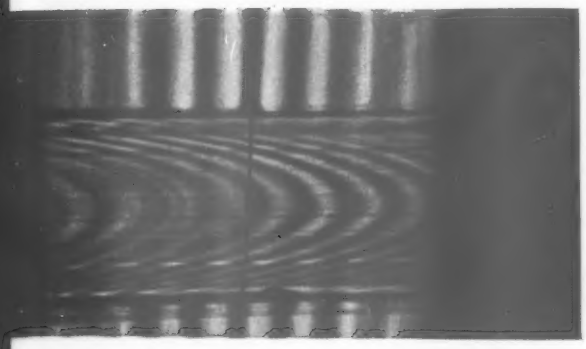
'Vycor' is here again of special interest. Measurements by Saunders (1942) show that whereas at ordinary temperature its thermal expansion is about twice that of fused quartz, at 300° C they have equal expansion rates.

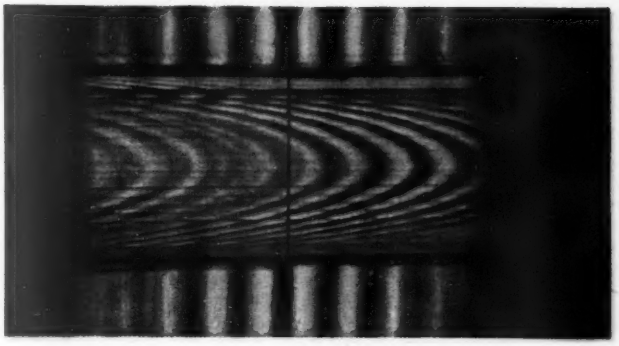
TABLE I

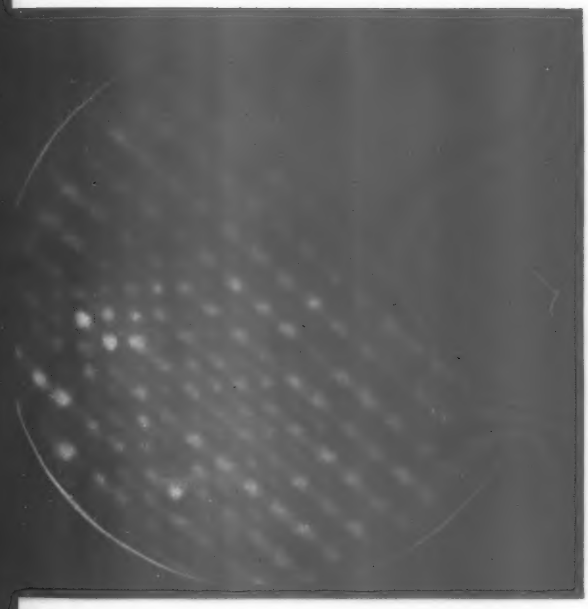
The Percentage Chemical Composition, Linear Thermal Expansion Coefficient (α) and Softening Points of some Glasses of Importance for Chemical, Heat Resisting, and Electrical Apparatus Purposes

	Chemical and Heat Resisting				Electrical Apparatus					
Chief Constituents	Fused Silica	Vycor	Pyrex and Hysil	Direct Flame Cooking Glass	High Pressure Mercury Vapour Lamp	Soft Lead for Bulb and General Sealing	Mercury Arc Rectifiers	Hard Glass Electronic Devices	For Sealing to Tungsten	For Sealing to Molybdenum
SiO_2	100	96·3	80–81	57·5	58·7	56·6	72·9	75·0	77·0	71·2
B_2O_3 ..		2·9	12–12·5	5·7	3·0	0·2	14·4	18·2	15·4	14·6
Al_2O_3		0·4	3	19·5	22·5	0·8	3·0	1·0	1·1	2·5
CaO		—	0·2	6·5	5·9	—	3·1	0·3	0·4	2·9
MgO		—	—	9·2	8·4	—	—	—	—	—
BaO		—	—	—	—	—	—	—	—	—
PbO		—	—	—	—	30·2	—	—	—	—
Na_2O		0·02	—	1·10	1·1	5·1	2·4	3·4	4·6	3·6
K_2O		—	4	—	0·2	7·2	4·2	1·9	1·9	4·0
$\alpha \times 10^8$										
20°–100° ..	45	80	320/330	410	340	930	—	—	—	—
20°–350° ..	—	—	—	—	—	—	—	—	350	410
T_g–M_g* ..	—	—	825	1000	1350	—	—	—	—	—
Softening Point (viscosity, $\eta \equiv 10^8$ poises)	1630°	1420°	780°	—	920°	625°	—	—	—	—

*The values for the temperature range lying between T_g and M_g are quoted in order to illustrate the big increase in thermal expansion coefficient at the transformation temperature, T_g, referred to on page 10 and in Fig. 1.



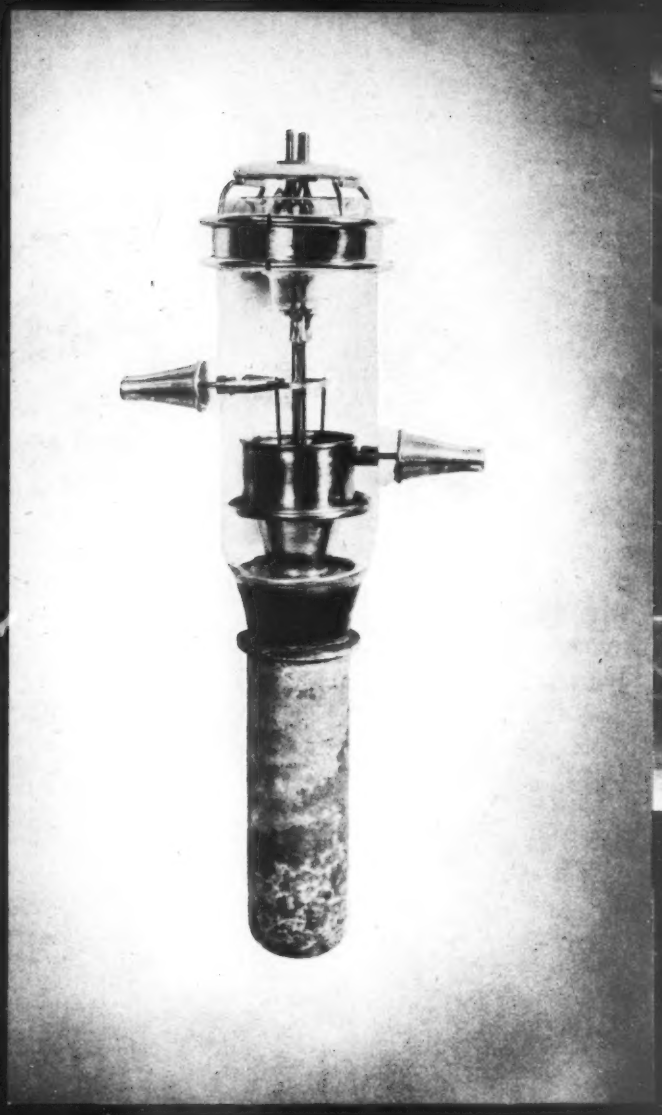




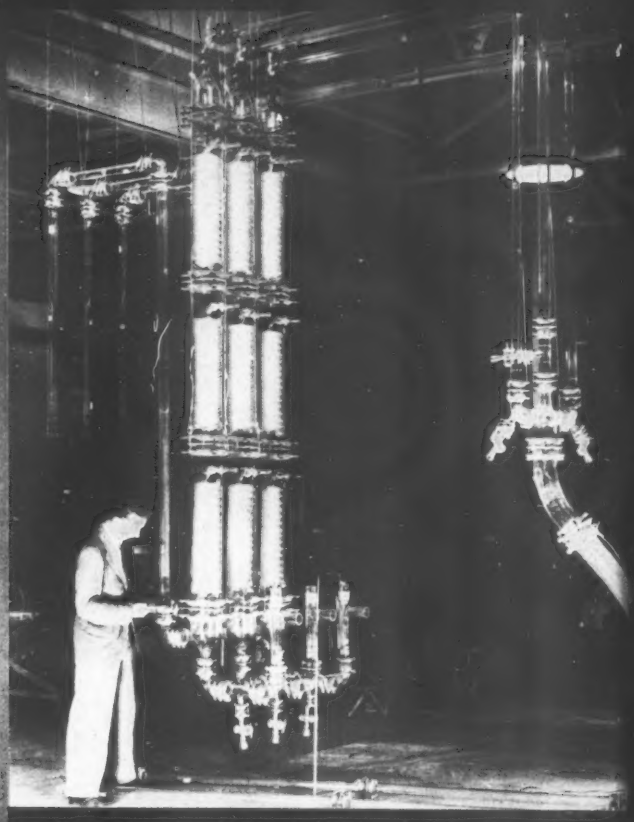
left and right (References figures 10 and 11): Colour strain pat-seen in the Babinet compensator through the edges of glass plates ered with stresses of 3·0 kg./mm.² (figure 10) and 7·5 kg./mm.² re 11). The black band corresponds to maximum stress. Corre-ding to the greater stress, the displacement of this band relative e fiduciary black line is greater in figure 11 than in figure 10.

m left (Reference figure 9): Colour strain pattern of a tempered ghened') circle of plate glass ¼ inch thick when viewed in a iscope provided with a whole wave tint plate. Motor car wind us of tempered glass show a similar pattern.

Bottom right (Reference figure 17): Colour pattern, seen in a polar-iscope, of one element of a radio-valve. The thick tungsten wires were coated with glass before they were sealed to the glass envelope at the "pinch" (the solid flat portion obtained by compressing the sides of the original tube). Maximum stress occurs at the glass-metal boundaries corresponding to the yellow-orange colour; lowest stress corresponds to the green coloured region. Slighter stress bands occur at AB where a wide glass tube has been sealed to a narrower one and left imperfectly annealed, and at CD just above the "pinch". again owing to lack of annealing.

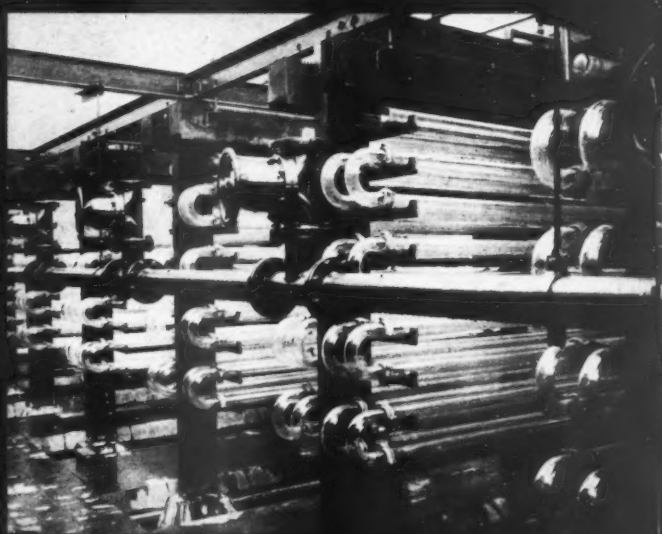


A water-cooled high-power Tetrode illustrating modern developments in glass-to-metal seals. (Reference figure 15)

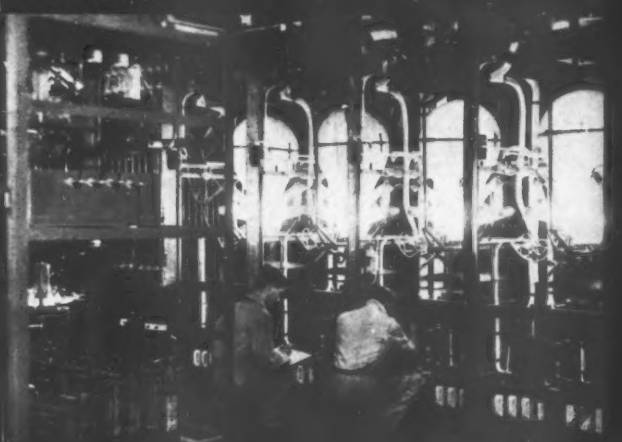


Large-scale system of condensing towers in operation at a chem factory. (Reference figure 3)

Modern use of the lathe in building up large-size glass plant. (R ence figure 4)



Open air glass tubular cooling system in a hydrochloric acid plant. (Reference figure 2)



An installation in operation of glass mercury-arc rectifiers with electrodes of tungsten sealed into glass. (Reference figure 16)

By increasing the alumina content of a glass, chemical resistance to alkalis as well as to water and acids is improved; and when silica is replaced by alumina the thermal expansion coefficient remains practically unchanged, so that the thermal endurance remains high. The high viscosity of such glasses, though increasing the difficulty of melting and shaping them, means that they have very high softening points. They find use at present for mercury vapour lamps, for glassware capable of withstanding the naked gas flame, and for tubing for the combustion of organic substances by microanalysis. Other fields for their use may well develop.

Table I summarizes the compositions and linear thermal expansion coefficients of some glasses of high chemical and thermal endurance.

Since fracture of glass occurs on sudden heating or cooling, owing to the excessive tensions set up between unequally heated layers, another method applied to moderately thick glass (say $\frac{5}{16}$ in. or more) to increase its thermal resistance is to temper or 'toughen' it. This process is described below, under 'The Mechanical Strength of Glass.'

The value of the deformation point will also determine the temperature range within which glass can be usefully employed. It is defined as the temperature at which, under a light load, deformation can just be perceived in a sensitive apparatus for measuring the thermal expansion right up to incipient softening; and it corresponds to M_g on the thermal expansion curve in figure 1. The softening point is higher and may be defined as the temperature at which the viscosity is 10^8 poises. As recorded in Table I, glasses of high softening point, approaching 1,000° C, are now available, in addition to fused silica and 'Vycor.'

The photographs of large scale technical plant, figures 2 and 3, are illustrations of the extent to which its transparency, together with high chemical and thermal endurance, as well as sufficient mechanical strength, have enabled glass to be brought into service. Pipe lines, of diameters up to twelve inches, are in extensive use for the conveyance of liquids, including strong acids, with massive glass control valves in the latter case, and have proved to be thoroughly satisfactory. The photograph (figure 4) indicates how, in building up massive apparatus, the modern glass blower uses a lathe to support and rotate the article under construction.

THE MECHANICAL STRENGTH OF GLASS

The mechanical strength may be determined through the tensile strength, that is, the load or force per unit area which just causes rupture in a freely hanging, vertical test piece; through the modulus of rupture determined by loading laths or rods suspended between two points of support, the quantity measured being $f = \frac{3\,Wl}{2\,b\,d^2}$ where f is the modulus of rupture, W the load, l the distance between the supports, b the width, and d the thickness; or through impact tests, usually carried out by dropping steel balls of different weights from a known height on to a sheet of glass suitably supported in a frame.

The tensile strength values recorded for glass vary between 3 and 8 tons per square inch, values low in comparison with those of metals, yet high enough to provide a considerable range of use for the material. But besides its rather low mechanical strength, glass is brittle, and broken fragments of it have great cutting power and are therefore dangerous. The problems constantly before the glass manufacturer have been to increase the margin of mechanical strength, and to evolve methods to prevent injury from sharp fragments if fracture occurs. Before indicating the partial solutions of these problems, the following summary of some of the results of numerous studies during the past fifteen years on the mechanical strength of glass may be helpful to the reader.

(1) Glass is the most perfectly elastic of solids. Its compression strength is very high and has probably never been determined with reliable accuracy. Glass always breaks through excessive tension.

(2) Despite its apparent rigidity, glass at ordinary temperatures acts as a liquid of very high viscosity which, in the case of commercial soda-lime-silica glass, may be as high as 10^{48} poises (F. W. Preston, 1942) or, from measurements at Sheffield, extrapolated from values at 200°–300° C, as low as 10^{24}.

(3) No clearly defined variation in strength is brought about by changing the composition of the glass. Other factors mask any variation if it occurs.

(4) The load-bearing strength (modulus of rupture) is lower at ordinary temperatures than it is either at 500° C or at −200° C (Preston 1942; Jones and Turner 1942).

(5) While measurements of the optical, thermal, electrical, and various other physical constants

of glasses give closely agreeing results on similar test specimens, mechanical strength measurements vary very widely; so much so that determinations have to be treated statistically.

(6) The value of the tensile strength or modulus of rupture of glass has a definite meaning only if associated with a test piece of standard dimensions. Probably when determined on comparatively large pieces the value will not change greatly with size. But the modulus of rupture of strips increases as the width diminishes, as indicated in figure 5 (Holland and Turner, 1934). On small test pieces (up to 30 cm. has been tested) the value also changes with the length between the points of support. The effect of dimensions is most strikingly demonstrated in the enormous increase in tensile strength when glass is drawn down from thin rods to very fine fibres, as indicated in figure 6, which combines results by A. A. Griffith (1920) and E. J. Gooding (1932). Extremely fine fibres have been prepared of tensile strength as high as 800 tons per square inch when freshly drawn. The dimensions of the test piece also influence the strength values of metals, as Karmarsch (1858) found in determining the tensile strength of metal wires. But the increase of strength with diminishing diameter is far greater with glass than with metals, and efforts to utilize this unique phenomenon in glass are referred to later.

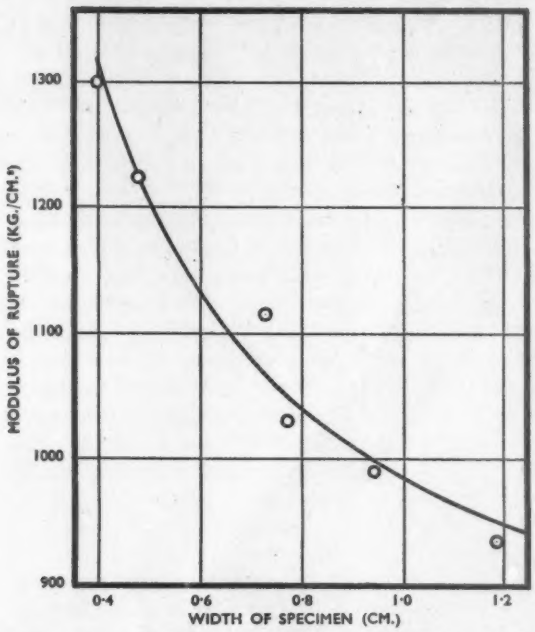


FIGURE 5 – *Effect of the width on the value of the modulus of rupture of sheet glass in the form of strips.* (*After Holland and Turner.*)

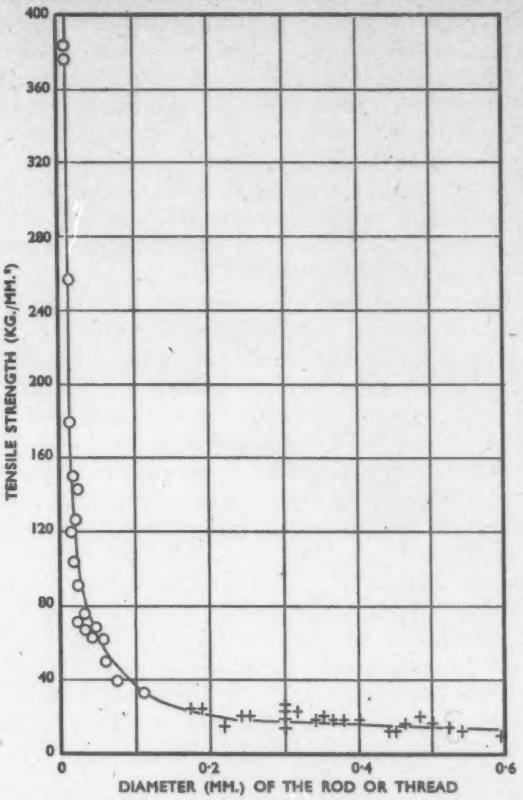


FIGURE 6 – *The relation between the tensile strength and diameter of glass rods and fibres.*

○ *Measurements by A. A. Griffith* (1920)
+ *Measurements by E. J. Gooding* (1932)

(7) Any methods which either remove flaws or keep them closed bring about an increase in strength. The modulus of rupture steadily rises with the degree of polishing applied to a strip of glass which has been cut from a large sheet with a diamond leaving its edges with small fissures of differing depth (Holland and Turner, 1936). Sealing these flaws completely by heat raises the strength to its highest level. Keeping the flaws closed by loading the glass so that this serrated edge is in compression leads to the same result. Etching with hydrofluoric acid, which rounds out existing flaws, also enhances strength.

(8) The time interval during which the load is applied influences the strength value found.

Impact and loading tests, therefore, may be expected to yield different results. Much greater loads can be applied for a very brief interval than when loads are sustained (Preston, 1942). Indeed, careful experiments have shown (Holland and Turner, 1940) that only when the load applied is reduced to 30 per cent. of the mean breaking load as determined in the usual way by loading for a few seconds, do specimens of glass survive fracture indefinitely. An empirical relationship, $t = {}_a L^b$ was deduced connecting the time before fracture occurred; L is the load and a and b are constants, with $b = 12{\cdot}8$.

(9) The fracture pattern of glass is connected with its strength value. Anything which enhances strength leads to growing complexity (forking of cracks) in the pattern. Narrow strips of glass with diamond-cut edges which break with a simple straight fracture, develop radiants, more and more complex, as the flaws in the edges are progressively reduced by polishing, either mechanically or by fire. This relationship continues to hold good for glass which has been strengthened by tempering. The photograph in figure 7 shows the fracture produced by the impact of a steel ball on lightly, moderately, and severely tempered plate, the complexity of the pattern increasing with the strength value found.

It is obvious from what has been said that in the normal use of glass, the factor of safety to be allowed must be considerable, and it should be determined with some reference to the dimensions of the glass to be used. Further, any treatment which reduces the number and dimensions of flaws, or which keeps flaws closed, will enhance load-bearing values.

For application to glass in general, the most effective way of adding to the strength is by tempering it. The result is to 'freeze in' compressive forces at the surfaces, which retard the opening up of flaws. Only when a very considerable tensile stress is then applied are these compressive forces neutralized so that the piece of glass becomes liable to fracture. The process of 'toughening' glass by quenching it from the soft state has long been known, 'Rupert's drops,' mentioned by Merrett (1662), being a familiar example; but the successful application on a large scale has been carried out only during the past fifteen years. Difficulties associated with the homogeneity of the glass, and with uniformly heating and then chilling the pieces under treatment, were the cause of earlier failures. The Glaceries de St. Gobain, France, attained success in 1929 with glass in its simplest form, namely, flat pieces, and shortly afterwards heat-treated and strengthened plate glass came into widespread use for motor-car wind screens. Figure 8 shows the principle involved in its manufacture. The glass is heated uniformly to a temperature of about 610° C, raised from the furnace and rapidly and uniformly chilled by a cold air blast. The exterior becomes rigid while the interior is still hot and plastic, resulting in the setting up of considerable compressive stresses acting on the outer layers, with tensile stresses in the interior.

It is possible by this treatment to increase up to tenfold the load-bearing strength and resistance to impact, whilst the resistance to torsion is greatly enhanced; but, in practice, tempering is usually controlled so as to result in an increase of strength of three to six times that of the original plate. Thus, the lightly, moderately, and severely tempered specimens, shown in figure 7 (A, B, and C),

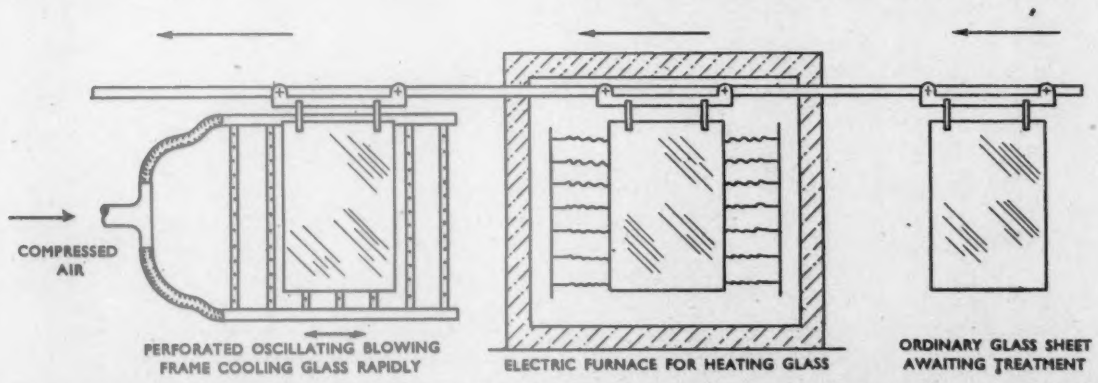

COMPRESSED AIR
PERFORATED OSCILLATING BLOWING FRAME COOLING GLASS RAPIDLY
ELECTRIC FURNACE FOR HEATING GLASS
ORDINARY GLASS SHEET AWAITING TREATMENT

FIGURE 8 – *Diagram illustrating the tempering ("toughening") of plate-glass by exposing both sides of a uniformly heated plate to an air blast.*

were so treated that the maximum tensions were 2·0, 4·0 and 6·5 kg./mm.^{2} respectively. The coloured photograph (figure 9) shows the typical pattern obtained through the face of the plate when viewed in a polariscope provided with a whole-wave mica plate. Figures 10 and 11 were taken through the edges of plates viewed in the Babinet compensator. The plates had been tempered so that the stresses were 3·0 and 7·5 kg./mm.^{2} respectively, obtained by chilling them from their maximum to the normal temperature in 240 and 55 seconds, respectively.

Each motor wind-screen, it may be mentioned, is subjected during inspection to a mechanical test, such as with a hammer, and is examined for its strain pattern in polarized light.

As illustrating in a striking way the successful control now applied to this tempering process, figure 12 shows the front of the glass pavilion erected by the Glaceries de St. Gobain to house their products at the Paris Exhibition of 1937. The walls are of hollow glass blocks and the curved staircase up to the entrance consists of tempered plate glass up and down which thousands of persons walked daily. Tempered plate, both transparent and black, has been used successfully in buildings with large glass frontages to ensure resistance to sudden changes of temperature. With experience, the process of tempering has been extended to glass objects of less simple shape; for example, to well glasses used in miners' lamps; to lenses to be set in concrete; and to domestic articles like drinking tumblers. One of the most striking applications some seven years ago was to large insulators for high tension power lines. In North America, as also in France, glass insulators for telephone, telegraph, and high tension lines have had widespread application. In Britain,

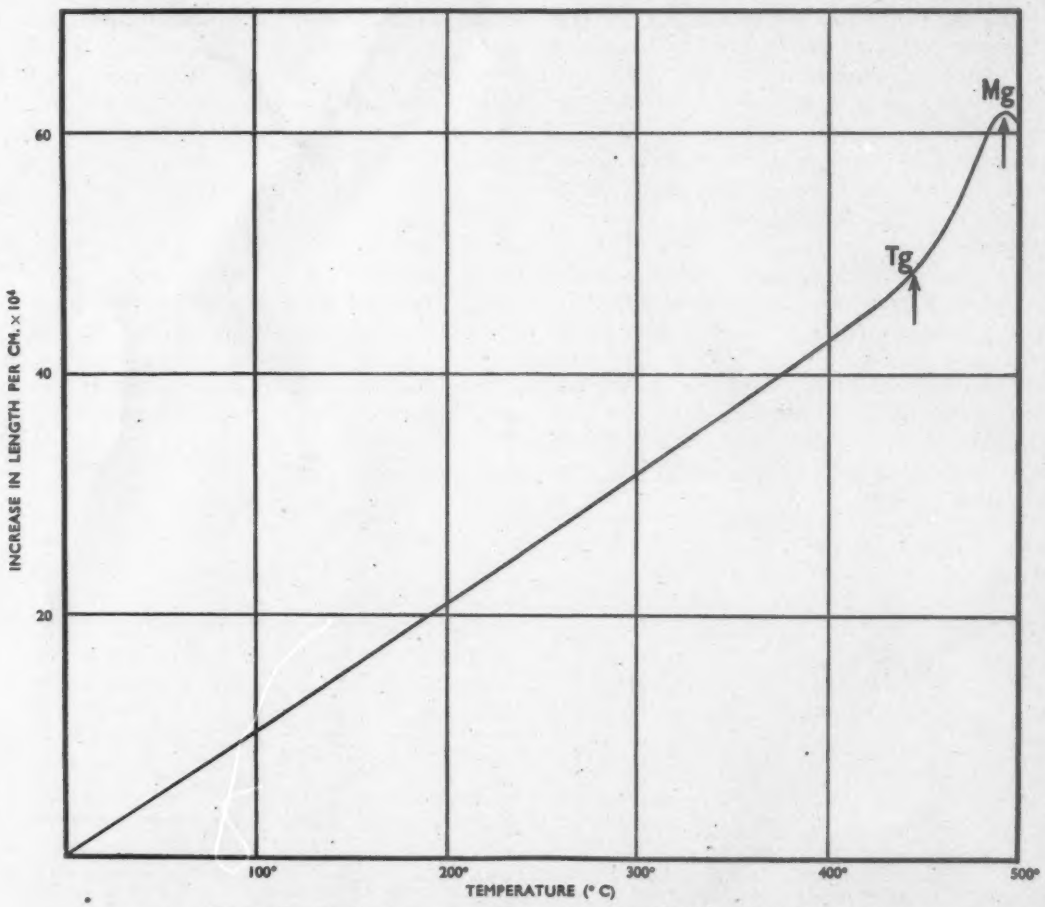
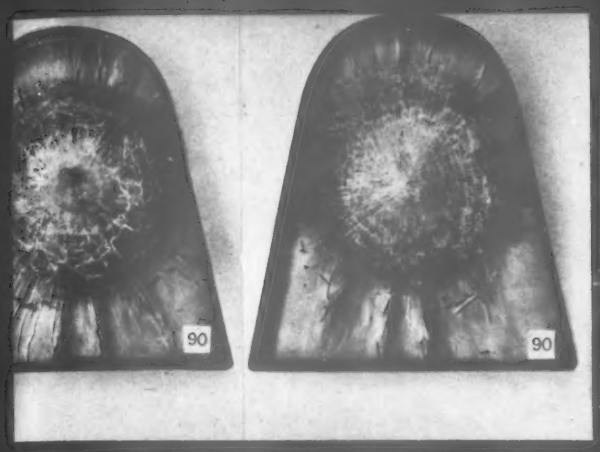
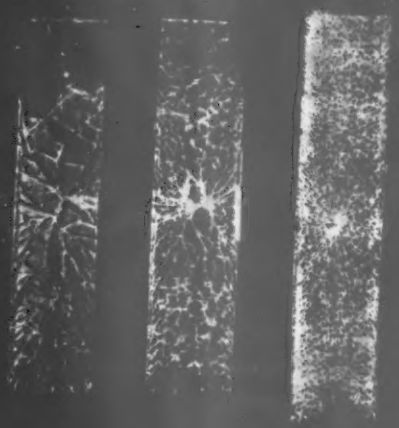


FIGURE 1 – *Thermal expansion curve of a soda-potash-lead oxide-silica glass from ordinary temperature to the deformation stage. The curve steepens at intervals even at temperatures below* T_g (445° C).



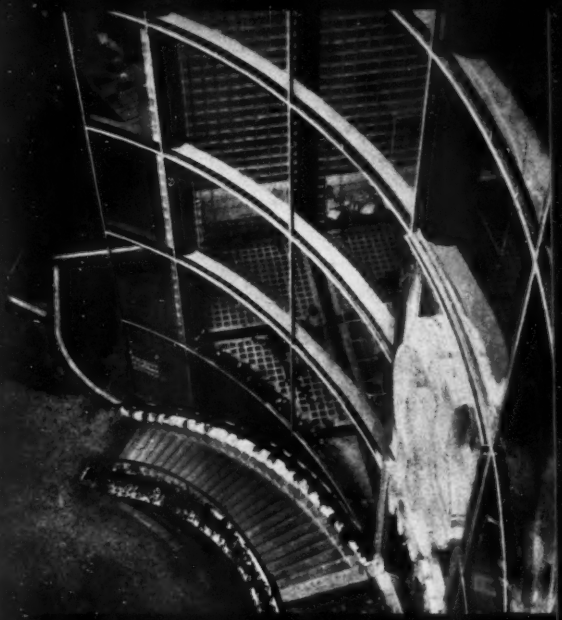
k and front of a bomb aimer's window after impact from an piercing ·303 bullet. (Reference figure 14)
eft: Front of the panel. Right: Back of the panel.



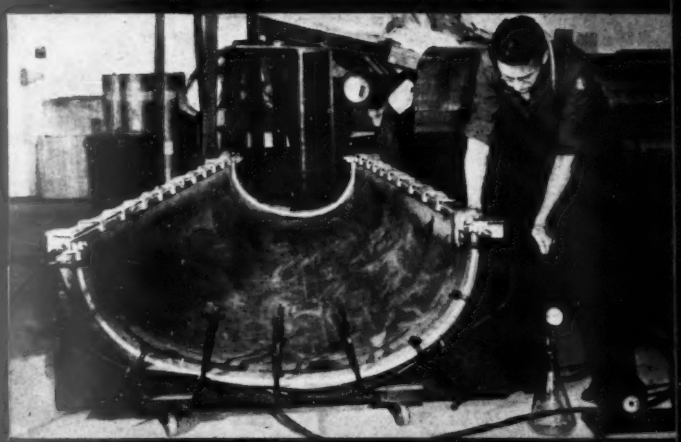
Tension 2 Kg/mm.² (A) 4 Kg/mm.² (B) 6·5 Kg/mm.² (C)

patterns of glass obtained by dropping a steel ball. (Reference Left: (A) Slightly tempered. Centre: (B) Moderately toughened") glass. Right: (C) Severely tempered ("toughened")

d high-tension glass insulator in position on a service line. e figure 13)



The Pavilion at the Paris Exhibition, 1937, erected by the Glaceries de la Cie de Saint Gobain, of glass blocks and with a stairway constituted of tempered ("toughened") plate glass. (Reference figure 12)



Preparation of glass fibre-reinforced plastic fuselage for an American aeroplane. (Reference figure 26)

Twisting yarn from glass thread. (Reference figure 21)

Hanks of glass fibre drawn by the old continuous process. (Reference figure 19)

Glass fibres (coarse) used as packing material providing grea area in distillation columns for the production of industrial (Reference figure 24)

A loom at work weaving glass fibre. (Reference figure 25)

Glass fibre produced in continuous blanket form by the modern steam-blown process. The illustrations show the blanket being cut into f and suitably backed. (Reference figures 22 and 23)

porcelain insulators have been of such high standard that they have held the field against glass; but the application of tempering to high tension glass insulators by one firm has given them noteworthy advantages over all other types. Their load-bearing and impact resistance are high. Figure 13 is a photograph of such an insulator on one of the power lines of the Central Electricity Board, South Wales.

In regard to protection from injury due to fractured glass: when strengthened by tempering, the edges of fragments resulting from breakage may be rough and cause abrasion, but they have practically no sharp cutting action like ordinary glass and can be handled with impunity.

The other method of dealing with the problem of broken glass, namely by lamination (that is, by inserting a thin interlayer of a plastic material such as cellulose acetate or vinyl acetate between two glass sheets or plates), is too well-known to need description. It finds application in war-time for goggles, for bomb-aimer's windows in aeroplanes, and for the windows in tanks. A bomb-aimer's window consists usually of several plates of glass separated by plastic interlayers. The two photographs (figure 14), show respectively the front and rear of a tested panel constituted of five plates, $\frac{3}{16}$ in., $\frac{1}{4}$ in., $\frac{3}{16}$ in., $\frac{3}{16}$ in., $\frac{3}{16}$ in., laminated with four plies of cellulose acetate each $\frac{25}{1000}$ in., the panel being used with the $\frac{1}{4}$ in. plate outwards. In the test, the screens are mounted at 45° to the line of fire and attacked with 0·303 Mark I ammunition having a specified striking velocity. No splinters must be detached from the rear face.

Tempering by immersion in molten salt baths has also been applied for the production of glass cooking ware intended to withstand direct heating over a flame. In this case, the composition of the glass (Table I) gives it a high softening point and annealing temperature, so high in fact, that, when it is heated over a flame in any ordinary cooking process, the stresses set up as the result of the original quenching are not released, and the vessel retains its high mechanical and thermal resistance.

GLASSES AND METALS IN COMBINATION

Combinations obtained by the deposition of silver, copper, platinum, or gold on glass surfaces, either to produce mirrors or for decoration, have long been known. Aluminium, deposited by evaporation, has been added to the list and is to provide the reflecting surface of the 200 in. telescope. By spraying aluminium on tempered plate glass to form a grid, an efficient and attractive type of electric radiator has been made. In all the above cases, except that of the aluminium-glass radiator, no considerable rise of temperature is involved in the normal use of these combinations, and the layer of metal is very thin. In consequence no marked stresses are set up between glass and metal. It is far otherwise in the many and various electrical devices concerned with illumination and power transmission. Envelopes of glasses of different compositions and properties, in length from $\frac{1}{4}$ in. to several feet, and a considerable variety of different metals in wire, rod, foil, tube, or cylinder form enter into the various combinations. Some are very complicated in character, as illustrated, for example, in figure 15 of a water cooled tetrode, and the mercury arc rectifiers (figure 16) in which the poles are made of tungsten rods which glow at yellow heat during use.

Owing to the great difference in heat conductivity between the metals and glasses, stresses must inevitably be set up at some stage of the cooling operation after sealing (see figure 17), and also during use if heavy currents are passed. The general problem is so to choose the materials and to proportion the several parts to be sealed as to prevent the stresses set up from exceeding the maximum tensile stress of the glass employed in the particular shape and thickness. It has long been accepted as an axiom that the thermal expansion coefficients of any pair of glasses, or glasses and metals, to be united should be very nearly the same. Actually this is by no means the only important factor. Indeed, as Houskeeper (1923) and other workers, such as Hull and Burger (1928), have shown, there are various other ways, particularly the use of soft glasses and malleable metals, and the graduation of the thickness of the glass and metal to the area to be united, by which successful seals can be obtained even when the differences of thermal expansion are such as to operate against success.

In general, the factors which make for successful sealing are:

(1) Close similarity of the thermal expansion coefficients of the two substances to be sealed, whether glass to glass or glass to metal.

(2) Bridging the gap between two materials of considerable difference in thermal expansion by the use of one or more glasses having rates of expansion intermediate between the two extremes. In Britain, in addition to a wide

range of glasses for making the envelopes, there are commercially available eleven 'inter-seal' or 'graded' glasses with a range of linear thermal expansion coefficient from 380 to $1{,}020 \times 10^{-8}$, with nearly uniform differences of 60–70 units between them.

(3) The use of soft glasses and of malleable metals. The use of a cushion between the metal and the main body of the glass ensures a successful seal in certain cases. Thus, copper wires are usually coated with dehydrated borax. Also, Hull, Burger, and Navias obtained a successful seal between iron and a lead glass after coating the wire with a film of a soda-lime-magnesia-silica glass such as is used in electric bulb envelopes.

(4) The use of metals with clean surfaces, free from scale as well as from pits, grooves, scratches, or hair lines, although adherence is often promoted when the metal forms a thin film of oxide which dissolves in the glass. (Platinum is an exception.)

(5) Careful annealing of the glass seal.

(6) The design of the parts to be sealed with particular reference to thickness, area, and angle of contact.

Close similarity of thermal expansion coefficients is required not merely at ordinary temperature but over the whole range from room temperature to near the sealing point. The rate of thermal expansion of glasses between these two points is not uniform. The linear coefficient often rises sharply at intervals by some 5–15 per cent. and, at a certain temperature, known as the transformation temperature, T_g, it may increase by

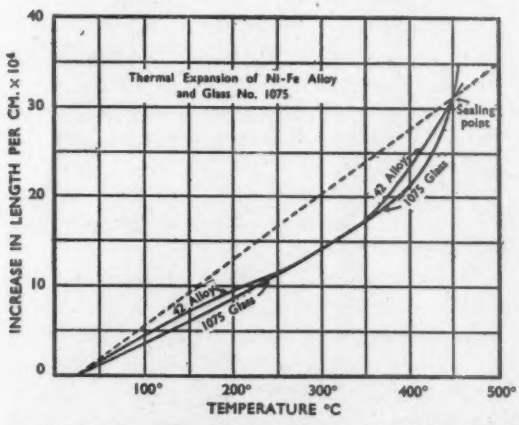


FIGURE 18 – *Thermal expansion curves of the nickel-iron alloy No. 42 and of glass No. 1075 to which it is sealed.* (*After Hull, Burger, and Navais.*)

200 to 1,000 per cent. Figure 1 (p. 10) is the thermal expansion curve of a lead-containing glass used in certain radio valves. In general, the metals also do not possess uniform rates of expansion. Those which have been widely used for sealing to glass, with their linear expansion coefficients ($\times 10^8$) between 0° and 350° C, are platinum (940), tungsten (440), molybdenum (550), and copper (1,690). Platinum has long been used successfully because the common alkali-lead oxide and alkali-lime glasses have linear thermal expansion coefficients ranging round 860 to 950. When tungsten and molybdenum were introduced into metallic filament lamps, glasses of closely agreeing thermal expansions were devised to provide sealing media. In addition to the four metals mentioned, the 'Fernico' alloys of nickel and iron, the coefficients of expansion of which vary widely according to the composition, have been used extensively both alone and with a thin sheath of platinum or copper. The iron chromium alloys also find extensive use in modern electronic devices. Figure 18 shows the extent of the match obtained by Hull, Burger, and Navias (1938) between an iron-nickel alloy (Fernico No. 42), containing Fe 57·8 per cent., Ni 41·5, Mn 0·5, Si 0·2, and the glass (No. 1075) of composition SiO_2 34 per cent., B_2O_3 28, Al_2O_3 7, PbO 29, Na_2O 2.

There are instances, however, in which similarity of thermal expansion coefficient is not an adequate guide to successful sealing either of two glasses or of a glass and a metal. Thus, it is possible for a clear glass and an opal glass to have almost precisely similar thermal expansion coefficients over a wide temperature range, yet the sealed glasses are readily fractured unless attention is paid to the difference between their annealing temperatures and the necessity of arranging some compromise temperature. It is also possible to obtain a very close seal between glasses having a 10 per cent. difference in thermal expansion rates, provided that the surfaces have been polished to give precise contact and that, after union by heat, the annealing is carefully performed. Further, iron has always been more difficult to seal direct to glasses than is copper, despite the fact that its thermal expansion coefficient is so much nearer than that of copper to those of the common glasses. An important factor in preventing the accumulation of excessive stresses is the ability of one or both members of the combination to yield to stress. This condition is fulfilled (1) if the viscosity of the glass is relatively low and the metal is malleable, (2) if

either or both be used in thin layers. Now the viscosity of the lead glasses at 550° C is about 1,000 times less than that of the alkali-lime glasses (Boow and Turner 1942), and at least 10,000 times less than that of Pyrex and Hysil. At ordinary temperature the differences are probably still greater. The glasses containing lead oxide are accordingly more readily capable of yielding to stresses than other common types. It is noteworthy that not only has the practice of glass blowers for generations been to melt round a platinum wire a bead of soft lead-containing glass which will form a junction with the walls of a glass apparatus, but that many of the successful modern sealing glasses contain from 20 to 30 per cent. of lead oxide. For example, the three special glasses devised by Hull, Burger, and Navias (1941) all contain approximately 30 per cent. PbO. Amongst the metals, copper is specially malleable, and because stresses will comparatively readily deform it, it can be successfully sealed to a wide range of glasses. One end of a tube of copper, of thermal expansion coefficient $1{,}670 \times 10^{-8}$, can be sealed to Pyrex glass and the other end to a lead glass. The success of these operations depends on tapering off the walls of both glass and copper tubes, so that they are very thin at the junction; the seals can then yield to stresses, and accordingly remain intact.

It is in no small measure due to procedures in which attention is given to the area, thickness, and angle of contact of the glass and metal, as advocated by Houskeeper in 1923 and developed still further by modern workers, that so much success has been achieved in building up modern electronic and other electrical devices in which glass and metal are united.

GLASS FIBRE AND ITS INDUSTRIAL USES

Some of the unique properties of glass find special application when it is drawn into filaments, (figure 19), although transparency in the ordinary sense no longer exists. The glass fibre industry has become one of great importance, and war conditions have enormously stimulated it.

Glass fibre is sterile, fire-proof, highly resistant to water, and generally chemically inactive. It exposes a very high surface per unit mass and, in bulk, it includes so much air that it is highly efficient for heat and sound insulation. When drawn from glass free from alkaline oxides, its electrical resistance is very high and it is used for electrical insulation. Its uses vary also with the diameter of the fibre, and both coarse and extremely fine fibres are made according to need. As stated in the preceding section, the tensile strength of glass increases enormously as the diameter of a thread is diminished. With this high tensile strength and small diameter goes 'bendability' or capacity to form loops and knots. The successful production of woven fabrics from it depends on the use of the commercially finer fibres now drawn. Finally, new ways are being sought for taking advantage of the extremely high tensile strength which glass filaments possess.

Four processes have been in use in the past ten years for drawing glass fibres, two of them for short fibres and two for continuous fibre. The principle underlying the production of continuous fibre is illustrated in figure 20. The glass is melted electrically in a tubular furnace in which the bottom or trough portion contains minute orifices through which molten glass emerges and forms 'tears.' The operator seizes the end of a tear, and rapidly draws from it a thread which is then directed towards and over a drum which by its rapid rotation carries on the drawing process at some 6,000 feet per minute. These tubular or trough furnaces may be of hard porcelain or sillimanite or other refractory material; but as the orifices in such material undergo corrosion, thereby enlarging their diameters, platinum troughs are now widely used. The standard practice has been to use a trough pierced by two parallel rows of holes, each row fifty-one in number. The one hundred and two filaments are drawn together over a combining pad (shown in figure 20), where they are lubricated to prevent mutual scratching, and are united into a continuous thread. Recently, in order to expedite production, troughs with four rows of fifty-one holes have been introduced, making two hundred and four filaments, which are combined into a single thread. These threads are at a later stage twisted together into a yarn, which may combine as many as twelve threads, or 2,448 filaments.

The steam blowing process is used for bulk production. Ten or more platinum troughs are set at the bottom of a large chamber fed continuously with molten glass from a large tank furnace. A tubular blowing device is located just below the orifices of the platinum troughs. High pressure steam directed downwards draws the filaments from the orifices at a high velocity into a chamber below, where they are lubricated, gathered into the form of a continuous blanket some three inches thick, and then transferred to a continuous

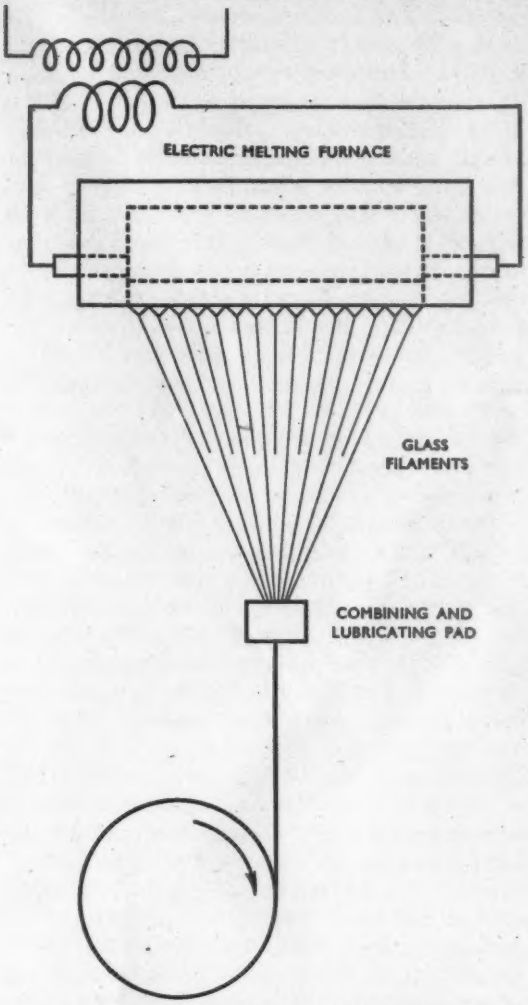


FIGURE 20 – *Diagram illustrating the drawing of glass fibres by the continuous process.*

conveyor (see figures 22 and 23). At the end of the conveyor the blanket is cut up by a guillotine, and may be backed by canvas coated with adhesive. In blanket form the material is used for heat and sound insulation, in buildings; for air filtration; and in some chemical processes; while in war it is used in ships and for many other purposes. The number of specific applications is quite large. The photograph (figure 24) shows coarse glass fibre used as the reactive surface in large scale distillation.

A considerable part of the continuous fibre made is woven into tape, ribbon, and cloths of varying textures (figure 25). The electrical fibre in the form of thread is used for winding copper wire for armatures or in the form of tape or cloth for cables. Its higher electrical and heat insulating values make it possible to run a motor so wound at a heavier overload than when cotton fibre is used as insulator.

Glass fibres combined with plastics are finding special uses. Thus, the fibre produced in mass by the steam blowing process may be lubricated with Bakelite in solution, and the blankets after compression acquire sufficient stiffness to be handled better than the untreated blanket in large scale insulation work.

An entirely different development from any of the foregoing uses starts with the recognition of the great tensile strength of glass filaments. The fibres, either in parallel lengths or in the form of cloth, are embedded in a plastic material in such a way that the plastic is in direct contact with the glass fibre without intervening lubricant, that is, the plastic itself provides the protecting sheath for the glass fibre. The two materials, namely the glass fibre and the plastic, are then laminated at a low pressure. The combination results in a material of high tensile strength. In the following table, the results of tests carried out with sections designed for aeroplane bodies from aluminium, from plywood, and from glass fibre-reinforced plastic (figure 26) are in favour of the last-named from the point of view of mechanical strength, and practical use is being made of the results.

TABLE II

Comparison of Strength of Fuselages of Different Materials

Fuselage Structure	Weight of Section Tested (lb.)	Destructive Load (lb.)	Strength to Weight Ratio
Glass cloth—balsa plastic ..	78	2590	33
Aluminium ..	70	1550	22
Birch plywood ..	86	1580	18

CORRIGENDUM

In October 1944 issue, page 159, figure 1—"hollow spheres" should read "solid spheres."

Dramatic moments in the history of science in Britain

ALLAN FERGUSON

Scientific discovery is not such a cut and dried affair as Francis Bacon would have had us believe. It has its flashes of inspiration and thrills of excitement. British phlegm on such occasions would deprecate Pasteur's Gallic promiscuity of osculation, and would certainly frown upon an Archimedean indifference to propriety; but that does not mean to say that British scientists are unmoved by such dramatic episodes as Professor Ferguson here describes.

The working life of a man of science is commonly supposed to be even and noiseless in its tenor, and singularly lacking in colour and in incident. The truth (not over-clearly recognized) is that the true man of science is at heart an artist, with all an artist's intuitions, all an artist's sensitivity. Kekulé, who was an inveterate dreamer—his day-dream on a Clapham omnibus in the eighteen-fifties, when the atoms gambolled before his eyes, was the origin of the *Structurtheorie*—has summed up one aspect of the scientist's activities in these sagacious words: 'Let us learn to dream, . . . then perhaps we shall find the truth; . . . but let us beware of publishing our dreams before they have been put to the proof by the waking understanding.'

FIGURE 1 – *Henry Cavendish* (1731–1810).
(From the drawing in the British Museum.)

Not that the scientific mind and character are to be classified under any one head. There are many mansions in the house of science, and there is room alike for the enthusiastic Davy, for the gentle and retiring Darwin, and for the morbidly shy and taciturn Cavendish (who, as one of his biographers testifies, uttered fewer words in a life of nearly eighty years than any other man, not excluding a Trappist monk).

Truly there are dramatic moments enough and to spare in the life of a man of science, moments which would certainly be recognized as dramatic by Davy or by Rutherford, but which equally certainly would not be recognized as such by the cold-blooded and cautious Cavendish. For the real drama of the moment may, or may not, be in the eye of the actor; it may be better appreciated by the audience, and, indeed, its significance may not be fully appreciated by them until long after the event. Nor need the event be momentous—the dramatic effect is not always, or necessarily, commensurate with the greatness of the occasion. Thus, when Newlands in 1866 read before the Chemical Society of London a paper in which he pointed out that, if the elements were arranged in the order of their atomic weights, there was a periodic recurrence of similar properties, a distinguished and sceptical member of the audience asked Mr. Newlands if he had tried to see what happened when the elements were arranged in alphabetical order. Assuredly a dramatic moment, and one of which the drama is more apparent to the modern eye than it was to the mid-Victorian audience which heard Newlands expound his Law of Octaves, the precursor of the Periodic Law. The incident is at least a warning to misguided humorists.

More dramatic, and of a wholly different order of importance, was the scene between T. H. Huxley and Bishop Wilberforce at the Oxford meeting of the British Association in 1860.

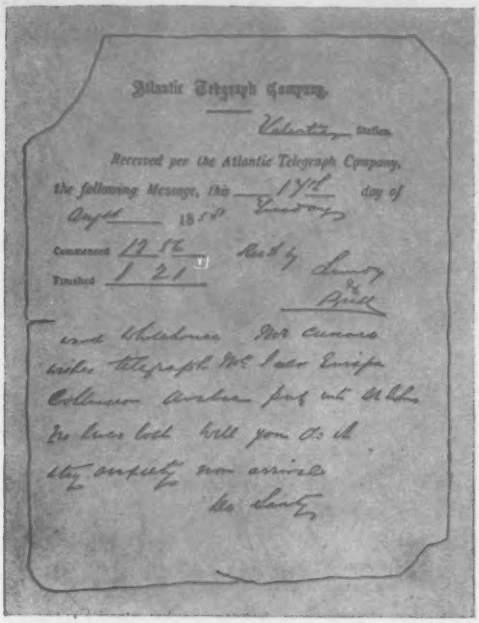
Darwin had published the *Origin of Species* in 1859, and the Darwinian theory loomed large at the 1860 meeting of the Association. The Bishop—a brilliant orator and skilled dialectician, but completely non-scientific—had been primed for his speech by the eminent zoologist, Richard Owen. In the course of his speech, he turned to Huxley and 'with smiling insolence begged to know, was it through his grandfather or his grandmother that he claimed descent from a monkey?' It was enough. Huxley, striking his hand on his knee, whispered to his neighbour: 'The Lord hath delivered him into mine hands.' Replying, Huxley, having traversed the scientific arguments advanced by the Bishop, turned to him and answered his personal question in terms so cuttingly sarcastic, so severe, and yet so dignified, that, as the full meaning of his retort became clear to the packed audience, the swelling roar of applause drowned his words. It is difficult to say what precisely were the terms of Huxley's retort. Eye-witnesses who have reported it agree in general but differ concerning the exact phrases. The report given by John Richard Green, the historian, is one of the most generally accepted of the many versions extant: 'I asserted—and I repeat—that a man has no reason to be ashamed of having an ape for his grandfather. If there were an ancestor of whom I should feel shame in recalling, it would rather be a *man*—a man of restless and versatile intellect—who, not content with an equivocal success in his own sphere of activity, plunges into scientific questions with which he has no real acquaintance, only to obscure them by an aimless rhetoric, and distract the attention of his hearers from the real point at issue by eloquent digressions and skilled appeals to religious prejudice.' A dramatic moment, indeed! So charged with emotion was the atmosphere that one of the lady members of the audience fainted.

FIGURE 2 – *Cartoon of Thomas Henry Huxley (1825–95) in middle age.*

A dramatic moment which has ever intrigued the present writer occurred some time in the eighteen-seventies, when Clerk Maxwell, who was engaged in editing some unpublished manuscripts by Cavendish, found that Cavendish, working in 1781, had arrived at correct views concerning electrical resistance, and had anticipated Ohm's Law by nearly half a century.

Cavendish was the oddest of mortals; shy, reserved, and taciturn, he was, as far as passion could be ascribed to his cold nature, consumed with a passion for exact measurements. For him, the external world was a series of objects which had to be weighed and measured as exactly as his resources would permit; and Cavendish's exactness was remarkable. Not less remarkable was his lack of interest in the publication of his work. Having satisfied himself, he cared little for the views of his contemporaries on his work, and was apparently not at all interested in the views of posterity. In his published work he left, however, some memorable pointers which posterity would have done well to note. Thus, in his paper dealing with the composition of the air, we read: '. . . so that, if there is any part of the phlogisticated air [nitrogen] of our atmosphere which differs from the rest . . . we may safely conclude, that it is not more than $\frac{1}{120}$ part of the whole.' One wonders whether another dramatic moment, that of the announcement—near the end of the nineteenth century—of the discovery of argon, a new constituent of the atmosphere, could not have been expedited by one or two generations, had chemists fully appreciated the significance of the words of Cavendish. Indeed, has he not some claim to a share in the honour of the discovery of argon?

To return to the subject of his electrical researches—more particularly those dealing with the measurement of resistance. The date (1781)


Atlantic Telegraph Company.

Valentia station.

Received per the Atlantic Telegraph Company, the following Message, this 17th day of August 1858

Commenced 12.52

Finished 1.21

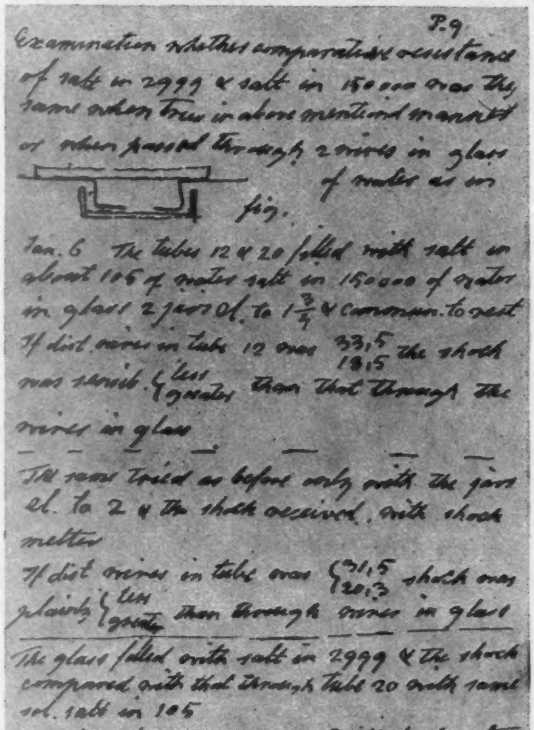
Sent by Lord Derby to Bull

and Whitehouse Mr Cyrus Field telegraph Mc Neile Europa Columbus Andes fast at Valentia Bay have lost hold you do all stop expect you arrived the Lord

FIGURE 3 – *One of the earliest telegraphic messages sent over the first Atlantic cable.*

must be borne in mind. The discovery of the voltaic cell was nearly twenty years ahead in the future and the galvanometer more than twice that interval away. Cavendish's only source of electricity was a frictional machine, and, remarkable to relate, he himself was his own galvanometer! His method was characteristic and unique. Having charged a battery of Leyden jars to a degree indicated by a pith ball electrometer, he discharged the battery alternatively through the resistances to be compared and in every case through himself as well, making a mental estimate of the intensity of the shock felt in his arm. The resistances, usually of salt solutions contained in tubes of known dimensions, were adjusted until the intensities of the shocks felt were adjudged to be equal. When we consider the method, the accuracy of the results obtained by Cavendish was truly astonishing. Thus, Maxwell's note on some figures given by Cavendish to show the relative resistance of iron wire and sea-salt solution reads: 'This is equivalent to saying that iron wire conducts 555,555 times better than a saturated solution of sea-salt. A comparison of the experiments of Matthiessen on iron with those of Kohlrausch on solutions of sodium chloride at 18° C would make the ratio 451,390. The resistance of iron increases, and that of the solution diminishes, as the temperature rises, and at a temperature of about 11° C the ratio of the resistances would agree with that given by Cavendish.' Maxwell was fully alive to the drama of his discovery and his enthusiasm knew no bounds. He repeated Cavendish's experiments by Cavendish's methods, and impishly insisted that visitors to the laboratory should try the shock-meter for themselves. The results were, on occasion, disastrous, especially in the case of one distinguished savant, whose concern for his own dignity far outweighed his interest in the experimental methods used by Cavendish.

If we consider the greatness of the consequences, there was drama on the Shakespearean scale in an interview which Halley, the astronomer, had with Newton in 1684—an interview which, more


P.9

Examination whether comparative resistance of salt in 2999 & salt in 150 000 was the same when tried in above mentioned manner as when passed through 2 wires in glass of water as in fig.

Jan. 6 The tubes 12 & 20 filled with salt in about 10 of water salt in 150 000 of water in glass 2 jars el. to 1 3/4 & Communn. to rest If dist. wires in tube 12 was 33,5 / 18,5 the shock was sensib. less / greater than that through the wires in glass

The same tried as before only with the jars el. to 2 & the shock received with shock melter

If dist wires in tube was 21,5 / 20,3 shock was plainly less / greater than through wires in glass

The glass filled with salt in 2999 & the shock compared with that through tube 20 with same sol. salt in 10 5

The jars el. to 2 & received with shock melter

If dist. wires in tube 20 was 1,5 shock was greater / less than through wires in glass

N.B. Great irregularity was found in trying the last experiment the cause of which I am unacquainted with

Therefore salt in 2999 conducts 2,5 times better than salt in 150 000

FIGURE 4 – *A page of Cavendish's MS.*

FIGURE 5 – *Sir Isaac Newton* (1642–1727).

The Manor house of Woolsthorp in the parish
of Colsterworth Lincolnshire, where Sr. Isaac
Newton was born; being his own estate.

FIGURE 6 – *Newton's birthplace, Woolsthorpe.*

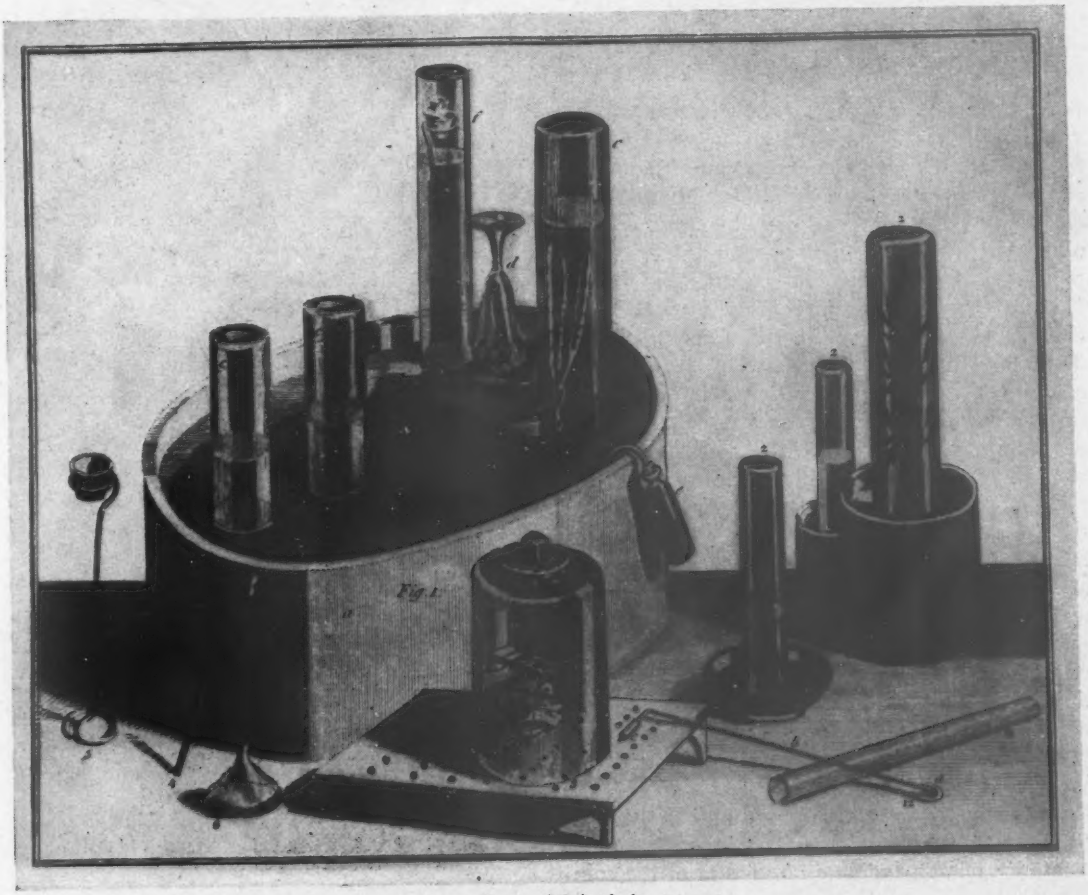


FIGURE 7 – *Some of Priestley's apparatus.*

than any other single cause, helped to determine the course of physical science during more than two centuries. The inverse square law of gravitation was then very much discussed by members of the young Royal Society. As far back as the early years of the seventeenth century, Kepler, after years of patient calculation, had enunicated and established his three laws of planetary motion, viz. that (*i*) the planets move in ellipses round the sun which is in one focus; (*ii*) the line joining sun to planet sweeps out equal areas in equal times; (*iii*) for different planets the squares of their periodic times are proportional to the cubes of their distances from the sun. Now, it is not a difficult matter to deduce the inverse square law from Kepler's third statement, and several astronomers, including Halley, had done this, but the inverse problem—*given the inverse square law, calculate the possible path of a planet*—proved to be baffling. Halley, Hooke, and Wren had discussed the problem together and, according to Halley, Hooke, who combined with his great natural gifts a pronounced tendency to boastfulness, 'affirmed that upon that principle all the laws of the celestial motions were to be demonstrated, and that he himself had done it. . . . However, I remember that Sir Christopher was little satisfied that he could do it, and though Mr. Hooke then promised to show it to him, I do not find that in that particular he has been so good as his word.' At last, Halley took his wrestlings and questionings to Newton at Cambridge, and his amazement may be imagined when he found that Newton had solved the inverse problem and many other problems of celestial motions, but had put his papers aside, and could not lay hands on them! Can one imagine a twentieth-century aspirant to the honours of a Ph.D. degree pursuing his researches in so disinterested a fashion? The fact is that Newton found science a 'litigious Lady' and had an aversion to publication comparable with that of Cavendish. It required all Halley's tact, enthusiasm, and powers of persuasion to force Newton to put forward his views in connected form; and there was more than one uneasy period, as when Newton threatened to suppress the manuscript of the third book, having heard that the arch-claimant, Hooke, was putting out assertions of priority. But Halley triumphed, and in July 1686 the book received the imprimatur of Samuel Pepys, President of the Royal Society, under whose auspices (and at Halley's expense) the book was published. Surely, if we think of the mighty influence which the *Principia* exerted on the development of physical science, and try to realize what course that development would have taken had the *Principia* never been written, the meeting of Halley and Newton on that August day in the Cambridge of more than 260 years ago must rank as the most dramatic moment in the history of science in Britain.

Applied science has had its dramatic moments, and the tale of the laying of the first Atlantic cable is packed with drama. The epic story runs through all the gamut of the emotions—tragedy, comedy, farce (as when a naval expert asserted that 'no other machinery for paying-out was necessary than a *hand-spike* to stop the egress of the cable!'), triumphant fulfilment of the task, and the final failure of the cable after 732 messages had been sent over a period of three months. In assessing the successes and failures of the first attempts, it must be remembered that at the time they were made (1857–58) it was but twenty years since the first practical under-water line had been laid—across the Hooghly at Calcutta. This was a primitive affair, in which a pitch-coated wire was enclosed in split rattans covered with a serving of tarred yarn.

A great mass of preliminary work had to be done; the design and dimensions of the cable had to be decided upon, new paying-out apparatus designed, and methods of storing the cable aboard ship devised. These difficulties having been surmounted, the *Agamemnon*, lent by the British Government, and the *Niagara*, of the American Navy, sailed from Valentia, in Ireland, on 5th August, 1857. To the *Niagara* fell the task of laying the first half of the cable; this done, a splice was to be made in mid-ocean, when the *Agamemnon* would take up the task. But the story of the first effort is one of increasing difficulties and disasters, culminating in the breaking of the cable when 380 miles had been successfully laid. In the attempts made during the next year (1858) the ships met in mid-ocean, spliced the cable and sailed in opposite directions. One reads an almost incredible story of tempest (in which the *Agamemnon* almost turned turtle), partings of the cable, failing signals, danger of collision with passing ships and monsters of the deep (for on one occasion a playful whale barely grazed the cable), and disheartening rendezvous in mid-ocean and in Ireland. But *finis coronat opus*, and in August 1858, after a series of voyages that were one long succession of dramatic moments, messages were exchanged between the two continents. Yet the catastrophe was still to come.

(*Continued on page* 34)

Plant viruses

KENNETH M. SMITH

Viruses occupy a position intermediate between the living organism and the non-living chemical. They are extremely small, some of them being of scarcely more than molecular dimensions. No virus has hitherto been cultivated in a cell-free medium. These are some of the striking facts mentioned by Dr Smith, who describes and illustrates the effects of certain disease-producing viruses upon tomato, tobacco, and other cultivated plants.

INTRODUCTORY

The word 'virus,' which is derived from the Latin and means a poison, has come to be associated exclusively with a particular type of disease agent. Viruses are put in a class by themselves, and the characters which chiefly distinguish them from visible pathogenic micro-organisms are as follows: first, their extremely small size, ranging from just below the limit of vision down to molecular sizes; second, their close association with the living cell—no virus has ever been cultivated in a cell-free medium; and third, their interesting relationship with insects, upon which many viruses are dependent for their transportation to new hosts.

The economic significance of viruses is very great. No form of living organism seems to be immune from their attack, and the sum total of disease, loss, and suffering due to their activities is almost equal to that caused by the pathogenic bacteria. In addition, viruses are of very great scientific interest, and recent discoveries on their nature have attracted workers from many different fields. The physicist, the physical chemist, the biochemist, and the serologist have all made their contributions to recent advances in our knowledge of viruses, and much of this knowledge has been derived from studies on the viruses affecting plants. Viruses have also a considerable philosophical interest, occupying as they do a borderland position between the 'living' organism and the 'non-living' chemical. They possess, on the one hand, such indubitable properties of life as the power to multiply and mutate, while, on the other hand, they show many properties, such as the power to crystallize, which are more properly associated with a chemical substance [7].

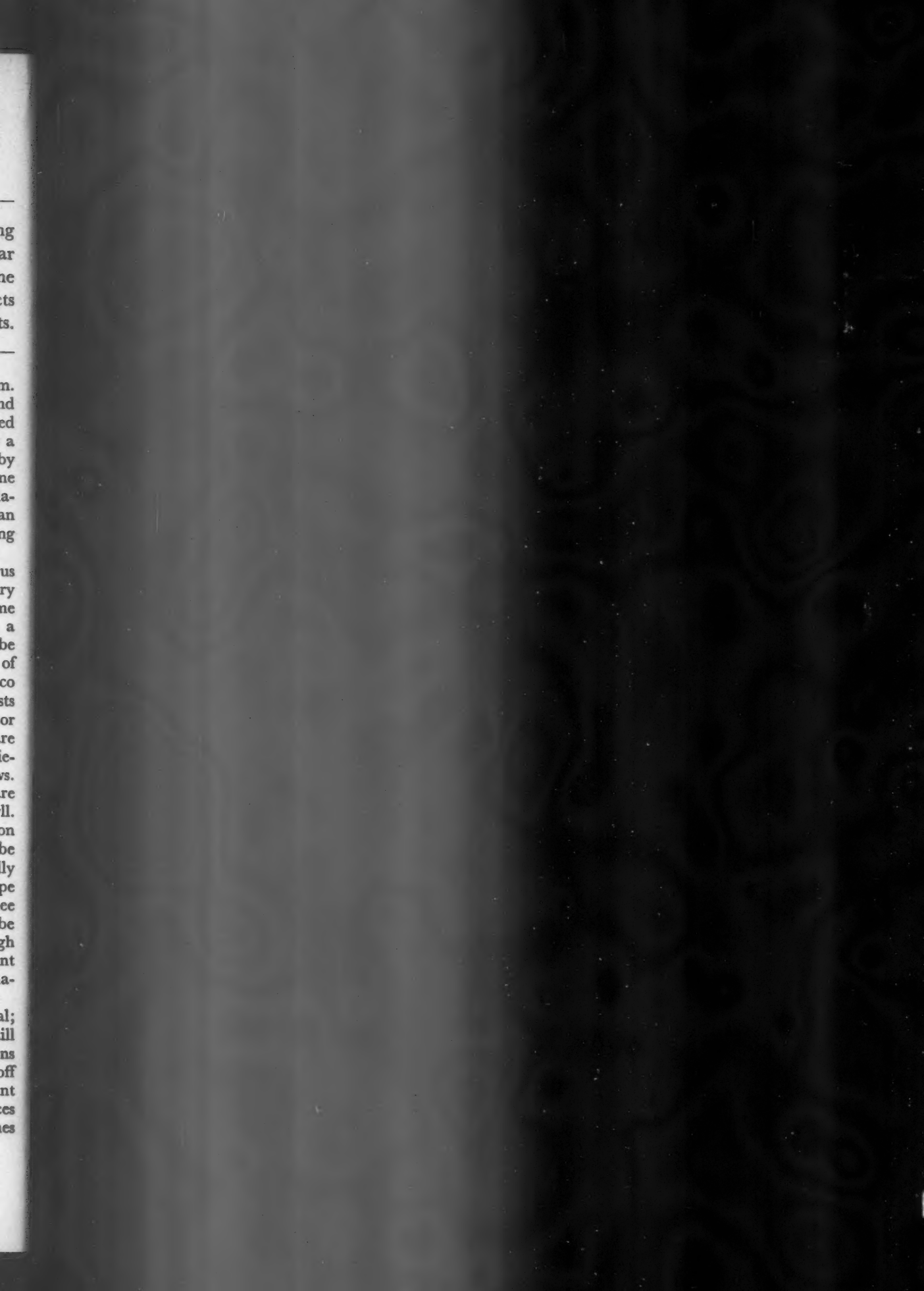
SOME SYMPTOMS OF PLANT VIRUS DISEASES

Until the more recent advances in knowledge opened up new methods of approach to the problem, almost the only criterion of the existence of a virus was the response of the infected organism. In plants the reactions are extremely varied, and some of the more striking symptoms are described and figured here. We can group together in a rough classification the types of response made by plants to virus infection; though it must be borne in mind that such a classification bears little relation to the viruses themselves, since one virus can cause many different types of disease according to the species of host plant affected.

One of the more common types of plant virus disease is known as 'mosaic,' and there is a very large group of mosaic-forming viruses. The name was originally given about 1885 by Mayer to a disease caused in tobacco by the first virus to be discovered, because of the fancied resemblance of the symptoms to a mosaic pattern. This tobacco mosaic disease is shown in figure 1, and consists of a mottling of the leaf with patches of light or dark green and yellow. Some mosaic diseases are very striking and may resemble a natural variegation, with their bright greens and yellows. Some of these bright yellow mosaic mottlings are fatal to the plant owing to the lack of chlorophyll.

Another type of symptom is the formation on the leaves of numbers of rings, which may be either concentric or single. These rings usually have a central spot, and viruses causing this type of symptom are known as 'ringspot' viruses (see figures 10 and 11). In extreme cases there may be as many as seven or eight concentric rings. Though various reasons have been suggested to account for this Liesegang phenomenon, the true explanation is probably not yet known.

As a rule, plant virus diseases are not fatal; there are, however, some viruses which do kill certain host plants. In these cases large lesions often develop in the leaves and stems, cutting off the supply of food and water, so that the plant wilts and dies. Another group of viruses produces malformations and distortions and sometimes



RE 1 – *Tobacco plant infected with the type or parent of tobacco mosaic virus. Note rather faint green mottle.*

FIGURE 2 – *Strain of tobacco mosaic virus causing bright yellow and green mottle. Compare figure* 1.

outgrowths on the under surface of the leaves. These outgrowths are called 'enations' and are really abnormal leaflets growing on the under surface of the normal leaf (see figure 5).

Some viruses stimulate or depress growth in plants. There is one which checks longitudinal growth and stimulates transverse growth, while another strain of the same virus acts in a precisely opposite manner. In this virus disease, giant flowers are sometimes formed in which the petals are green and borne at the end of a thick stalk about 1 in. long [3]. Occasionally viruses induce in ornamental plants the appearance of symptoms which improve their appearance. The attractive variegation in *Abutilon* sp., which at one time was largely grown, is due to a graft-transmissible virus. The change in colour of tulip flowers, known as 'breaking,' is caused by an aphis-transmitted virus. Such infected tulips which normally have self-coloured flowers give rise to flowers very delicately pencilled or flecked with white or yellow.

IMMUNITY AND VIRUS STRAINS

Since there is apparently no antibody formation in plants, there is no acquired immunity to viruses such as exists in the animal kingdom. There does exist against viruses in plants, however, an acquired immunity of a very limited type. This immunity depends upon the presence in the plant of a virus which is related in some way to the infecting virus. In other words, the cells of the plant must be already occupied by one virus which 'holds the fort,' so to speak, against the entry of the second virus; but this, in order to be excluded, must be similar in nature to the first. The presence of one virus in a plant is no protection against the entrance of other unrelated viruses to which the plant may be susceptible.

It will be necessary to explain here what is meant by 'related viruses.' Some viruses exist in a number of closely similar strains, a phenomenon which is not confined to plant viruses. It is met with in the foot-and-mouth and influenza viruses, for example. It is particularly true of the tobacco mosaic virus (figure 1), which frequently 'mutates' and gives rise to strains having an entirely different symptom picture while retaining physical properties similar to those of the type virus. Some of these strains or mutations are illustrated in this

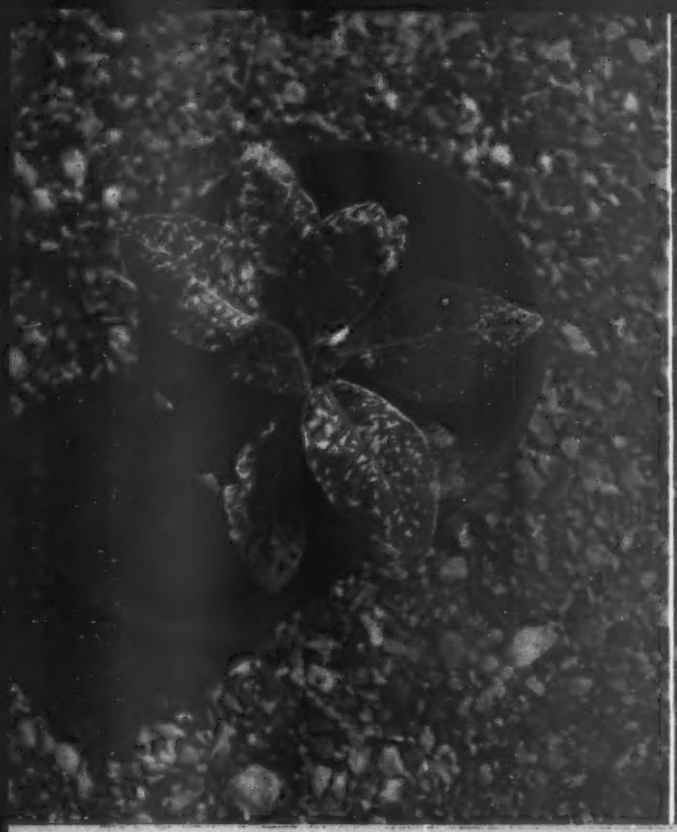


FIGURE 3 – *Another strain causing a different type of yellow and green mottling.*

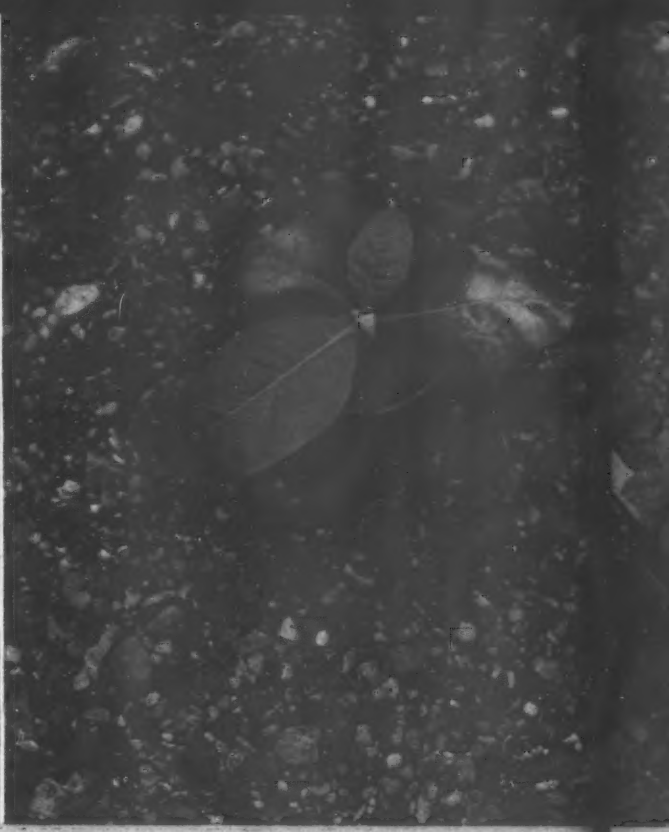


FIGURE 4 – *This strain produces no mottling but only intense yellowing, fatal to the plant. The illustration sho the beginning of the yellowing.*

GURE
gs.

FIGURE 5 – *A strain which produces peculiar outgrowths—enations—on the under side of the leaves. This virus was isolated from a cigarette.*

FIGURE 6 – *The same virus as in figure 2, showing effect on tomato.*

GURE
figure 2

GURE 7 – *A strain which gives rise to yellow and green*
gs.

FIGURE 8 – *A similar virus to that shown in figure 7.*

GURE 9 – *A bright yellow mosaic similar to that shown figure 2, but caused by an entirely different virus.*

FIGURE 10 – *One of the ringspot type of viruses, unrelated to any of the other viruses figured.*

FIGURE 11 – *Result of a cross-immunity test between two ringspot viruses: note the smaller rings, due to the second virus, developing among the larger rings caused by the first virus. This indicates that the two viruses are not related.*

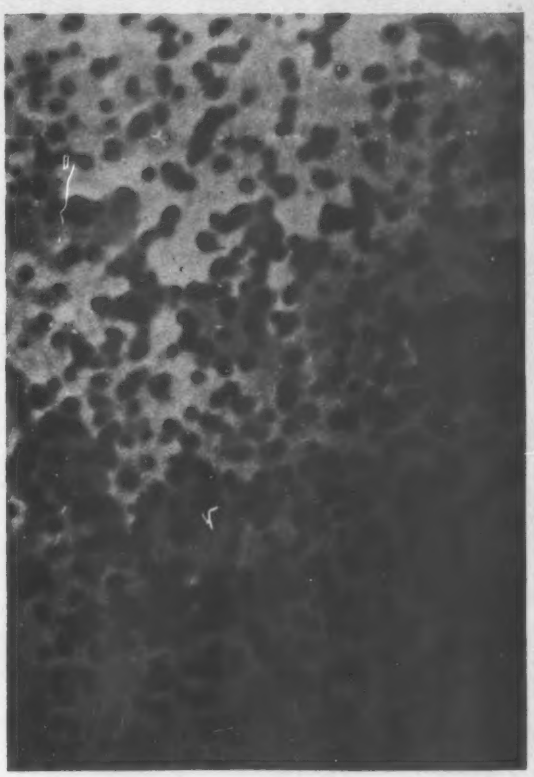
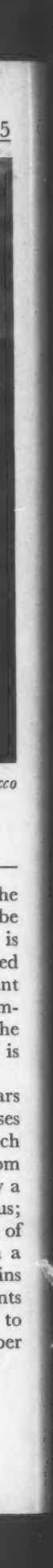


FIGURE 12 – *Electron micrograph of the virus of tobacco necrosis* × 38,000.

article. Figure 1 shows the type or parent virus which produces a green mosaic mottling on the leaves of the affected plant. From this can be derived strains which, as the illustrations show, produce very different disease symptoms. Some have a very bright green and yellow mottle (figure 2); another is entirely yellow, and this disease is rapidly fatal to the plant, which dies through deficiency of chlorophyll (figure 4). A third develops outgrowths or enations on the leaves (figure 5). In parenthesis it may be mentioned that this enation strain of tobacco mosaic virus was isolated from a cigarette. Yet another mutation produces little or no mottling on the plant, but is rapidly fatal because of the destruction it causes to the cells.

Between all the viruses causing these varied symptoms there exists the acquired immunity briefly referred to in a preceding paragraph. Each of these virus-diseased plants is protected from infection by any of the other viruses because all the strains are related, having arisen from the parent virus illustrated in figure 1. It should be understood, however, that if a healthy plant is inoculated with two or more of these related viruses *at the same time*, then all will enter the plant and the symptom expression will show a combination of the characteristics of each virus. The immunity is conferred only by a virus which is systematically spread throughout the plant.

Figure 9 shows a yellow mosaic which appears very similar to the other yellow mosaic diseases illustrated, but is in fact caused by a virus which differs profoundly in all its properties from tobacco mosaic virus. This disease is caused by a yellow mutant or strain of cucumber mosaic virus; it shows how deceptive from the point of view of diagnosis the symptom picture may be. Such a plant is susceptible to infection by all the strains of tobacco mosaic virus shown, and all plants infected with them are in turn susceptible to infection by this virus. The yellow cucumber



mosaic virus, however, protects the plant from infection by a green strain of cucumber mosaic virus, and vice versa. In one way, this kind of acquired immunity is a useful tool and can be employed to investigate a suspected relationship between two viruses giving similar but not identical symptoms.

It has been mentioned earlier in this article that one type of symptom caused by plant viruses is the formation of ringspots on the leaves. In all, about seven or eight of the ringspot-forming viruses have been described, and while some of these are apparently related, others are not, in spite of the similarity of their symptoms.

The result of a cross-immunity test is shown in figure 11. A tobacco plant fully infected with a virus forming large rings was inoculated with a second ringspot virus which gives rise to smaller rings. A leaf which showed numbers of the large rings was rubbed gently with sap containing the second virus. After the lapse of about a week, the smaller rings began to develop on the leaf, on and around the rings already there. In figure 11 can be seen both types of rings on the same leaf. The result of this test indicates that the two ringspot viruses are not related strains.

TRANSMISSION OF VIRUSES

Viruses differ from the majority of disease agents by their dependence, in a number of cases, upon insects to transport them to new hosts in the field. This is not peculiar to the plant viruses, and everyone is familiar with the part played by mosquitoes in the spread of yellow fever.

The relationship of viruses with insects is often very specific, and only certain types of insects—sometimes only one particular species—can transmit a particular virus. The insect carriers or 'vectors' of plant viruses are almost entirely confined to one Order, the Hemiptera, and are insects like aphides or leaf-hoppers which imbibe the plant sap by means of their suctorial mouth parts. This relationship between plant viruses and insect vectors is not a simple one and not very much is known about it. For example, opinion is divided as to whether plant viruses actually multiply inside the insects which transmit them, although there is good evidence that certain animal viruses, like that of yellow fever and a virus affecting horses, do increase inside their mosquito vectors. It has been shown [8] that in the main the plant viruses which are insect-borne fall into two groups: the 'non-persistent' type where the virus is quickly lost by the insect, and the 'persistent' type where the insect retains infectivity for long periods without access to a fresh source of virus. Most of the viruses belonging to the latter type can be spread only by insects and not by the mechanical inoculation of the sap. In the British Isles only two types of insect vectors are known, the aphides or plant-lice and the thrips. The latter, which are among the few insect vectors not belonging to the Hemiptera, transmit the virus of tomato spotted wilt, familiar enough to growers of tomatoes and ornamental plants under glass.

SOME UNUSUAL PLANT VIRUSES

Among the 150 or so plant viruses which have been described up to the present are a few which are unusual and exhibit some interesting characteristics. One of these, known as tobacco necrosis virus, occurs frequently in the roots of apparently healthy plants, particularly the tobacco plant. Except for the occasional formation of a few lesions on the first leaves of very young tobacco plants, especially if the leaves are in contact with the soil, this virus does not cause a disease at all, but remains confined to the roots. If, however, a few of the roots are ground up in a mortar and the resulting fluid is gently rubbed on to the leaves of tobacco or of any of the many other susceptible plants, then large numbers of lesions develop. It is thus possible to induce a severe disease in a plant by inoculating it from its own roots. This virus is not transmitted by insects but is carried in the water, or in the air, in particles of dead infected plant tissue. By these means it enters the soil and thence appears to gain access to the roots through some minute wound. It is necessary for entrance that there be a wound, however slight, and this is demonstrated by the following experiment. If a susceptible plant is grown in a water culture containing the virus, the roots do not become infected provided they were not previously wounded or damaged. If, however, the plant is grown in soil or sand containing the virus, then infection results, because the movement of the roots through the soil ruptures the root hairs, and this minute wound allows access to the virus. It is interesting that this virus has never been recorded outside glasshouses, although it has been found in the roots of plants in glasshouses in many parts of the world.

In 1935 a new virus suddenly appeared in a few tomato plants in the Bristol area and in one or two other places in England, and then disappeared again completely. It was, however preserved at various research stations and during

the past nine years has been subjected to intensive study. Perhaps more is known about tomato bushy stunt virus, as it is called, than about any other virus; but its natural method of spread has never been discovered, nor has any insect vector for it been found. It is interesting, therefore, to record that after nine years the virus suddenly appeared again, having been found in the summer of 1944 in tomatoes in the Worcester (England) area. Unfortunately it has not been possible to obtain any further information on this latest outbreak, nor could the origin of the infection be traced.

It might be said about the third unusual plant virus, in contradistinction to that of tomato bushy stunt, that less is known about it than about any other. Indeed, but for the fact that under certain artificial conditions it gives rise to symptoms, no one would be aware of its existence. This virus, to which the name 'paracrinkle' was given, was discovered by chance when scions of apparently healthy potato plants of the King Edward variety were grafted on to certain other varieties [5].

The main facts about this virus may be stated briefly as follows. It is present without symptoms in all potatoes of the King Edward variety, including the mutant Red King; it does not spread in the field to any other variety or plant; and no natural method of transmission is known. In the laboratory it can be transmitted only by means of grafts, and when spread by this method to certain potato varieties such as Arran Victory, a severe virus disease is produced. This disease can be transmitted indefinitely in series; in some potato varieties, such as President, the virus is carried without symptoms in the same manner as in the King Edward itself.

The existence of such a virus gives rise to a question to which it is difficult to find an adequate answer: How did the original King Edward seedling get infected with the virus? There is apparently no natural means by which the virus can spread and it has never been recorded occurring naturally on any other potato variety or other host plant. If the original King Edward seedling had come from abroad, one might suggest that the virus had some specific insect vector not found in Britain, but there is no evidence that this was the case. It was apparently first raised by a gardener in Northumberland, who called his seedling Fellside Hero; this name was later changed to King Edward. The parentage of the seedling is unknown [6].

The suggestion has often been made that the paracrinkle virus is part of the normal protein of the King Edward potato and that it behaves like a virus when introduced into other potato varieties [2]. While this is a tempting speculation, the available evidence does not bear it out, since, if the virus is normal protein, it should be transmitted through the true seed of the potato, and this does not occur [1].

SIZE AND SHAPE OF VIRUS PARTICLES

Although the majority of animal viruses, and probably all the plant viruses, are well below the limit of resolution of visible light, the application within the last few years of the exact methods of the physicist to the study of viruses has resulted in a great increase in knowledge concerning the virus particle itself. By means of X-ray diffraction, by ultrafiltration, and by means of the ultracentrifuge and the electron microscope, the size and shape of several viruses are now known with some degree of accuracy [4]. At present these methods can be applied only to the more stable plant viruses occurring in high concentration in their host plants. Very many plant viruses are very unstable, occur in low concentration, or are not sap-transmissible, and no information is available about the particle size of this type of virus. The particles of tobacco mosaic virus are rod-shaped; those of tomato bushy stunt virus are spheres (about 27×10^{-7} cm. in diameter.)

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Recent work on gaseous ions

A. M. TYNDALL

The conditions which determine the attachment of ions to surrounding molecules have been the subject of much research, but the published literature has been marked by many apparent discrepancies. Professor Tyndall, who with his collaborators in the University of Bristol has carried out fundamental work on gaseous ions, here gives an illuminating survey of recent advances. He shows that much previous uncertainty has now been removed.

It is well known that electricity is transported through electrolytes and gases by ions dragged through the medium with a velocity which is usually proportional to the applied electric field. The velocity in unit field is termed the mobility of the ion. Owing to the constant collision of an ion with the molecules of the medium its nature, e.g. its mass, cannot be determined by direct methods, such as the mass spectograph, applicable at low gaseous pressures. But some deductions may be made indirectly from the measured value of mobility and its variation with physical conditions. In this article we shall consider ions in gases, firstly in the pure state and secondly under controlled conditions of impurity.

It is now clear that all the early work was vitiated by the presence of dirty surfaces and traces of vapours such as water and organic compounds from tap grease. Owing to the polar nature of these molecules they are strongly attracted to an ion and form a cluster of molecules around it. The result is that the mobility of this ion cluster is markedly reduced; it becomes so mass-insensitive that the nature of the original ion may be quite masked.

PURE GASES

More recent measurements[1] in the Wills Physical Laboratory at Bristol, using an all metal glass apparatus to which modern gas and vacuum technique can be applied, have shown that, provided all sources of contamination are removed, the ions remain in the form they had at birth, i.e. a negative electron and a positive atom or molecule.

Under such clean conditions not only can the mobility of these ions be investigated in the gas in which they originated, but foreign ions may also be used. For this purpose ions of the alkali metals are very convenient; they may be produced from a glassy melt of Al_2O_3, SiO_2, and the oxide of the appropriate alkali metal. This is a mixture of high work function in which alkali metal atoms are present. If a bead of it is heated and charged to a positive potential, the alkali metal atoms evaporate as positive ions, because it requires less energy to remove an electron from the alkali metal atom than from the surface of the medium to which it is held.

Shorn of all circuit details, the method of measurement may be summarized as follows: A and B in figure 1 are perforated electrodes between which a steady electric field exists. Any

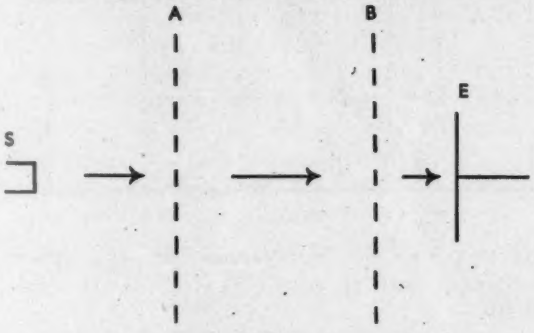

FIGURE 1

positive ions supplied from the source S which pass through A will be dragged by the field across to B. By applying a series of voltage pulses to ions in the neighbourhood of A, thin sheets of ions are admitted through A in regular succession and later reach B. Let the pulses be applied with a frequency n and the time taken for the ions to cross from A to B be T; let also the exit of ions from B be controlled by a similar set of pulses in phase with those applied to A. Then, if $n = 1/T$, each layer of ions arrives at B just as it momentarily operates like a shutter. The ions then move through it to the electrometer E. The

[1] TYNDALL. *The Mobility of Positive Ions in Gases.* (Cambridge University Press.)

same result occurs when $n = 2/T, 3/T, 4/T$, etc. Except in the immediate neighbourhood of these frequencies, no transmission of ions, and hence no electrometer current, occurs, and in practice the magnitude of the effect falls off as the critical value of n rises. The whole effect is somewhat analogous to the orders of a diffraction grating, and if the ions supplied are not homogeneous we have the possibility of analysis by the formation of a mobility spectrum. Figure 2 shows an example for a homogeneous source of sodium ions in argon[1]. The first 'order' of the spectrum is

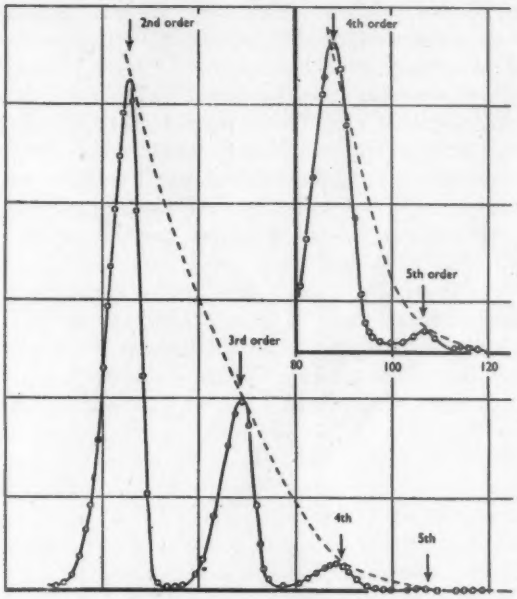

FIGURE 2

omitted and the fourth and fifth are shown separately with an enhanced electrometer sensitivity.

The mobilities of all the alkali metal positive ions in the five inert gases He, Ne, A, Kr, and Xe have thus been determined in the pure state. Each type of positive ion has its characteristic mobility in a given gas, and the relation between mobility k and the mass of ion M is shown in figure 3, where k^2 is plotted with 1/M.

Langevin derived an expression for the mobility of an ion on the assumption that the ions and the neutral gas molecules were elastic spheres of finite radius attracting one another by polarizing forces inversely proportional to the fifth power of the distance between them. Though a picture based on classical mechanics should nowadays give way to a wave-mechanical treatment of the problem, this has yet to be supplied. But in the present case a classical treatment can be used with some justification. Accepting this view we find that the linear relation between k^2 and 1/M given in the heavier gases indicates that the size of the ion within the chosen limits has no influence on mobility. The departure from linearity between k^2 and 1/M which is marked for neon and helium indicates that here the size effect cannot be ignored.

EFFECTS OF ADDED IMPURITY

In certain cases these graphs may be used as a mass spectrograph to determine the mass of other ions which may arise. Thus Powell and Brata, using sodium ions in nitrogen containing a trace of hydrogen, found an ion of mass 40. Presumably at the hot surface of the source a trace of ammonia was produced, giving rise to an ion $NaNH_3$.

Some years later Munson and the writer[2] followed this up by a detailed study of the effect of water vapour, added to the gas in small concentrations. Water molecules are strongly polar, and if one becomes attached to an ion a considerable amount of energy will be required to remove it. If more than one molecule attaches itself, then we may expect that the binding energy of any one of these molecules will decrease. The final number of molecules in the cluster will fluctuate about a mean value determined by the mean energy of the colliding particles, i.e. by the temperature.

The experimental method adopted to study this was to 'age' the ions in the presence of water vapour for a sufficient time to secure equilibrium before measuring their mobility. If equilibrium is thus reached, then a value of mobility should be obtained which is independent of the water vapour pressure, provided this is small compared with the gaseous pressure. Independence of concentration was found in this way between 0·1 and 2 per cent. water concentrations. Table I gives the mobilities so obtained: (*a*) refers to pure gas and unclustered ions, (*b*) to ions clustered with water vapour.

Application of the graphs of figure 3 to these results will give us an estimate of the number of water molecules in the cluster; the values so deduced in argon, krypton, and xenon vary between 5·7 and 6·4. But this estimate of, say,

[1] POWELL and BRATA. *Proc. roy. Soc.*, 1932, **138**, 118.

[2] MUNSON and TYNDALL, *Proc. roy. Soc.*, 1939, **172**, 28.

TABLE I

VALUES OF MOBILITY OF ALKALI METAL IONS

In cm./sec./volt/cm.

(*a*) *Unclustered ions;* (*b*) *clustered ions*

	He		Ne		A		Kr		Xe	
Ion ..	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)
Li ..	25·6	11·70	11·8	5·28	4·99	2·26	3·97	1·46	3·04	0·98
Na ..	24·2	11·15	8·70	5·25	3·23	2·25	2·34	1·43	1·80	0·94
K ..	22·9	11·85	8·0	5·26	2·81	2·19	1·98	—	1·44	0·92
Rb ..	21·4	12·8	7·18	5·38	2·40	2·10	1·57	1·37	1·10	0·87
Cs ..	19·6	13·4	6·50	5·48	2·23	2·18	1·42	—	0·97	0·83

six molecules is an upper limit, because we cannot be sure that the size effect can be ignored in the case of a cluster of larger diameter than an atom of the same mass. Indeed, a more sensitive test might well disclose that the value was less than six and varied with the nature of the ion.

On the latter point there is some independent evidence to this effect. Thus in electrolytes it is well known that the lithium ion is the slowest instead of the fastest of the alkali metal group. It has already been suggested that this is due to greater hydration resulting from the stronger ionic field at the surface of an ion of small diameter. It may also be noted that there is evidence in Table I of a similar effect on He and Ne, in which the mobility of the water-clustered ions passes through a minimum, and in which the lithium ion travels appreciably more slowly than the caesium ion. It is interesting to note that in 1933 Bernal and Fowler deduced that in electrolytes a lithium ion collected on the average four water molecules and the caesium ion none at all. Our view is that the number in gases is not greater than, and probably less than, six for lithium and still less but at least unity for caesium.

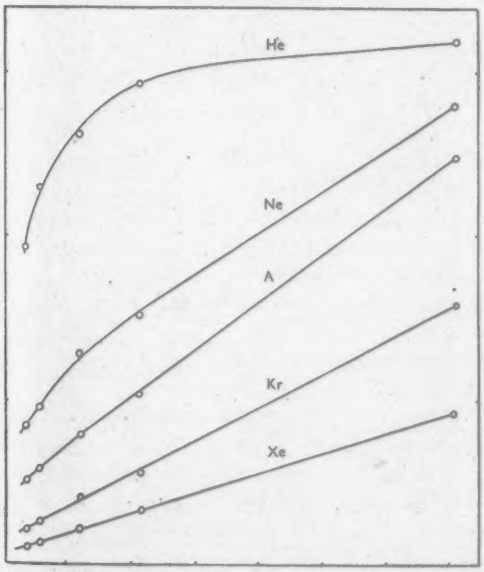

FIGURE 3

It is also interesting to study the earlier stages of cluster formation by measurements of mobility at much shorter ages. The results are significant. Two typical illustrations are given in figures 4(*a*) and 5(*a*) in which, as in figure 1, the electrometer current is plotted with pulse frequency. Though the resultant graph at first sight bears very little resemblance to figure 2, it may be analysed into two component groups (*b*) and (*c*) of different mobilities and showing several orders as in figure 2. By repeating the experiments without the presence of water vapour it was possible to identify the spacing in (*c*) with unclustered alkali metal ions. The more slowly moving ion (*b*) is clustered with several molecules. Although some dozens of cases were tested, the number of groups of ions present in detectable quantity was never more than two.

The relative abundance of these two groups varies from all unclustered at very short ages to

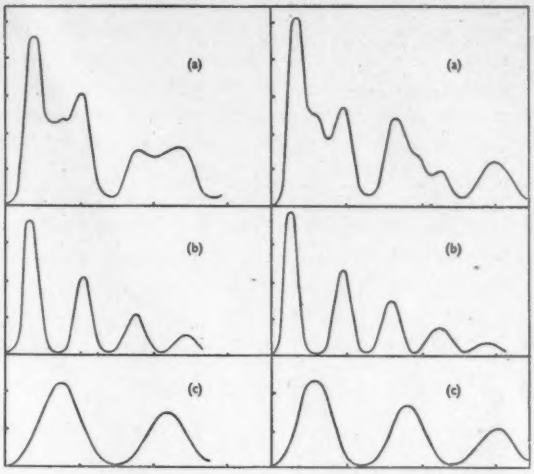

FIGURE 4

FIGURE 5

all clustered at long ages of ion. In other words, an ion in passing through the gas either acquires a full cluster or none at all, and the longer the life the more certain is the acquisition of a cluster.

MECHANISM OF ATTACHMENT

We may find an explanation of this phenomenon by plotting a graph of potential energy (V) of a system of two atoms for different distances between their centres (r). If a stable configuration is to be secured, then at some point the potential energy must have a minimum value as in figure 6 (a) and (b). The depth of the well D is a measure of the dissociation energy, i.e. the energy which must be given to the system to separate its parts to infinity. Thus (a) represents a more stable system than (b). For instance, if (a) applies to the union of an alkali metal ion with one water molecule, then (b) could represent the potential energy graph for an ion already clustered and near another water molecule.

The existence of this potential well does not mean that combination will necessarily take place when the two bodies approach one another. Under the attractive force, the bodies will acquire kinetic energy which may carry them through the minimum into the region of strong repulsion, from which they will spring apart again. Combination requires the presence of some mechanism to absorb this kinetic energy, so that the two bodies remain held near the bottom of the potential well. This mechanism may be provided by the presence of a third body or by vibrational degrees of freedom present once a cluster has started to form. Thus the probability of attachment of the first water molecule to the ion would be much less than that of subsequent molecules. This conception gives a qualitative explanation of the fact that unclustered ions can often be found in the presence of some water vapour, but that having attached one molecule the cluster quickly builds up to a given size with intermediate sizes sq transient as to remain unresolved.

NEGATIVE IONS

The attachment of water molecules to electrons in gases has never been fully studied. Electrons in the free state have a very much greater mobility in gases than positive ions, and therefore make fewer collisions with water molecules in a given journey. From that point of view negative ions behave as though they were less sensitive to the presence of water vapour as an impurity. But polar molecules do give rise to clustered negative ions during their passage, provided the concentration of impurity is high enough. Moreover an early observation by Powell and the author, in air not carefully cleaned, showed that electrons and strongly clustered negative ions can also exist together in the ionic stream.

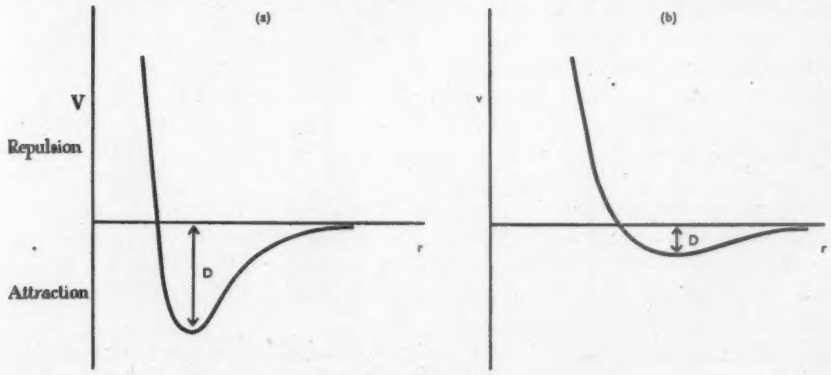

FIGURE 6

ATTACHMENT OF NON-POLAR MOLECULES

Since there is such direct evidence of the attachment of polar molecules to an ion, we

TABLE II

Ion	Gas	Temp. °K	ion clust.	$\frac{C}{(1-C)}$	n	Electron volts
Li^+	He	20	1·10	> 3	1	$> 0{\cdot}016$
		77		$\rightleftharpoons 1$	1	$\rightleftharpoons 0{\cdot}07$
		90		< 1	3	$< 0{\cdot}08$
	Ne	90	1·98	>10	3	$> 0{\cdot}13$
		195		$<1/10$	1	$< 0{\cdot}16$
	A	195	2·38	>10	2	$> 0{\cdot}25$
		290		$< 1/3$	1	$< 0{\cdot}29$
	Kr	290	3·09	> 10	2	$> 0{\cdot}31$
		360		< 2	1	$< 0{\cdot}35$
	Xe	290	3·84	> 20	2	$> 0{\cdot}42$
K^+	A	77		$< 1/10$	1	$< 0{\cdot}06$

must also consider the possibility of the attachment of non-polar molecules. Here the binding energy will in general be much less; but it will not be absent because the electric field due to the ionic charge polarizes a molecule in the neighbourhood of the ion, giving it an induced dipole of strength varying inversely with the fifth power of its distance from the ion.

The most favourable conditions for observation of such an effect will be: (*a*) an ion of small diameter to allow of a large polarizing field at its surface, (*b*) a gas atom of high atomic number, i.e. of high polarizability, (*c*) a low temperature which will reduce the chances of a bound molecule being knocked off during thermal agitation. Some successful attempts[3] are detailed in Table II. In column 5, C is the concentration of unclustered ions. If the current carried by a given ion is less than 10 per cent. of the whole in these experiments this ion might possibly escape detection. Hence the figures $C/(1 - C) > 10$ and $< 1/10$ in this column mean that no unclustered ions and no clustered ions were detected, respectively.

Let us first take the most favourable case for detection of attachment, namely the smallest ion Li^+ in the most polarizable gas, xenon. It is here not necessary to go to lower temperatures to observe complete clustering. Indeed, it is not possible to obtain the mobility of the free Li^+ ion in xenon in low fields. A rough estimate of the number of atoms (n) attached to the ion is given in column 6. In the case of Li^+ in xenon it is two.

For Li^+ in krypton similar results are observed at room temperature; though this is just about a limiting case, because at 100° C unclustered ions appear in large quantities and the clustered ion is estimated to contain only one gas atom instead of two.

On passing to the smaller and progressively less polarizable atoms A, Ne, and He, clustered ions are observed in large quantities only at progressively lower temperatures. Thus in neon there is no attachment at room temperature, or at 195° K, but it is marked at the boiling point of oxygen. In helium there is some evidence of a mixture of free and clustered ions at the boiling points of oxygen and nitrogen, but strong evidence of a predominance of clustered ions at 20° K (boiling hydrogen). The effect of reducing the polarizing field by using a larger ion is shown by substituting potassium for lithium. In argon no clustered potassium ions are found even at the temperature of boiling nitrogen.

An attempt has been made to estimate the binding energy in electron volts. The results in the last column of Table II for lithium show a gradual increase in value from helium to xenon. A larger value is obtained for a single atom than when it is one of two which are attached.

In conclusion, it may be claimed that these experiments clear up many apparent discrepancies in the literature of the subject.

[3] MUNSON and HOSELITZ, *Proc. roy. Soc.*, 1939, **172**, 43.

Islam and science: retrospect and prospect

(*Continued from page* 2)

The greatest botanist of Islam, Ibn al-Baitar (*ob.* 1248), flourished at too late a period for his work to exert any marked influence upon European science; but his botanical treatises, though based upon earlier writings, in sum represent a very notable advance.

So the story might be continued. Muslims of those past centuries regarded scientific knowledge as of the highest importance, and 'with interest came method: a rationalistic habit of mind and an experimental temper.' The rise and decline of intellectual activity and productivity remain inexplicable phenomena; but it is permissible to believe that what man has done man can do. A large part of Islam has yet to acquire educational facilities even remotely comparable with those of Europe or America, and until that defect is remedied it must be idle to expect her to recapture former glories. We do not doubt, however, that Islam represents a vast but untapped reservoir of scientific ability—with an unpredictable proportion of genius—which the world can ill afford to neglect.

Given the opportunity, Islam may again find a place in the van of scientific progress; and since some 100,000,000 of His Majesty's subjects are Muslims it would be most fitting were that opportunity to be offered by the British Commonwealth and Empire to that part of Islam bearing allegiance to the Crown.

Dramatic moments in the history of science in Britain

(*Continued from page* 21)

Electrical science was young, and knowledge was largely empirical. The electrician in charge (*not* Professor William Thomson, afterwards Lord Kelvin), believing that one cannot have too much of a good thing, insisted on working the line with the aid of a five-foot induction coil. The effect on the insulation was disastrous and the cable broke down completely in October 1858. Dramatic to the end, the cable's last coherent word was 'forward.' The engineers summed up the melancholy story in a sentence: 'High-pressure steam had been got up in a low-pressure boiler.'

There is no end to these dramatic episodes, but space presses, and one can only sketch a few of the very large number of dramatic moments in the history of science in Britain.

The life-story of Joseph Priestley (1733–1804), theologian, historian, and chemist, author of 108 published books, is packed with thrills. An indefatigable experimenter, he discovered many of the commoner gases, including nitrous oxide (or laughing gas), the first anaesthetic. And it was surely a dramatic moment when Priestley, searching for the action in Nature which purified the air vitiated by the respiratory processes in animals, found that air in which mice had previously been asphyxiated could be purified so that mice could again live in it, by simply keeping a sprig of fresh mint in a volume of the vitiated air, confined over water in a glass jar.

Dramatic, too, were the events on that day in 1807 when Davy, working at the Royal Institution, electrolysed moistened potash and discovered metallic potassium. Small wonder that, in an excess of delight, he scribbled 'capital experiment' in his notebook alongside his observations. In the long and distinguished history of the Royal Institution there are few more thrilling moments than this; but the outstanding event in its history happened on that day in the autumn of 1831 when Faraday, beginning his historic 'Experiments on the production of electricity from magnetism,' discovered the induction of currents.

To conclude, let us recall the announcements of the discovery of argon; of helium as a terrestrial element; of the electron; of the large-angle scattering of alpha-rays (which led Rutherford to the concept of the nuclear atom, and of which he said: 'It was quite the most incredible event of my life. It was almost as incredible as if you had fired a 15-inch shell at a sheet of tissue paper, and it had come back and hit you'); and, late but not least of these dramatic moments, the drama of the discovery of penicillin.

Celestial spectra

SIR HAROLD SPENCER JONES

The study of celestial spectra—of the sun, of stars, of nebulae, of comets—has made rapid progress during recent years. Thus an investigation of the spectra of comets has revealed the presence not only of C_2, CN, CH, OH, and other diatomic molecules, but of the triatomic molecule CH_2 and the isotopic molecule $C^{12}C^{13}$. The coronal spectrum has been almost completely identified, as have some of the lines of the spectrum of interstellar space; but the broad emission bands of supernovae still present a problem for solution.

The astronomer has the advantage over the physicist of being able to study matter under conditions that are not obtainable in the laboratory, such as conditions of very high temperature or extremely low density. It not infrequently happens, therefore, that lines or bands are observed in celestial spectra which have not been observed in the laboratory. The first instance of a line of unknown origin being detected in a celestial spectrum was provided in 1868, when Lockyer observed in the solar spectrum a prominent line in the yellow, close to but not identical with the well-known sodium lines. The line was attributed to an unknown element, which was called *helium*; nearly thirty years later terrestrial helium was first found in the air and in certain minerals. In this instance, the discovery of helium in the sun before it was found on the earth was due to its terrestrial scarcity, though cosmically it is abundant; it was not due to helium in the sun being under conditions not obtainable in the laboratory. It set a precedent for lines of unknown origin found in celestial spectra to be attributed to elements not known on the earth.

Somewhat different examples were provided by the observation of strong molecular absorption bands of unknown origin in the spectra of Venus and of the major planets. Within recent years it was suggested from theoretical considerations that the bands in the spectrum of Venus were due to carbon dioxide, and that those in the spectra of the major planets were due to ammonia and methane. These identifications were verified in the laboratory by passing light through a great length of the gas at high pressure; it was because of the considerable mass of gas required to produce detectable absorption bands that the bands had not previously been observed in the laboratory.

When the spectrum of the sun's corona was found to contain a number of unknown lines, they were attributed to an unknown element, which was named *coronium*. Many unknown lines were also observed in the spectra of the gaseous nebulae. Prominent amongst these are two strong lines in the green, which are responsible for the characteristic greenish colour of these nebulae. The lines were attributed to another hypothetical element, *nebulium*. With the advance in the knowledge of atomic structure, it came to be realized that there were no gaps left in the atomic sequence to be filled by such elements; coronium and nebulium could therefore not be unknown elements, but must be known elements under unfamiliar conditions.

The unfamiliar condition prevailing in the gaseous nebulae is the extremely low density; the density of the Orion nebula, for instance, has been estimated to be about 10^{-15} of that of air at normal temperature and density. Now an atom will not normally remain in any given energy level for longer than about one hundred-millionth of a second before it spontaneously off-loads its energy; but there are some energy levels in which an atom will remain on the average for seconds or minutes before emitting radiation. The spectral lines associated with transitions from atoms in these metastable states are not observed terrestrially because, even in the highest vacuum attainable in the laboratory, the energy is likely to be removed from the atom by collision with another atom long before the atom is ready to off-load it spontaneously. The chance of an atom radiating such a line is so highly improbable that transitions from metastable states are not permitted by the empirical rules that have been formulated; the lines produced by transitions from a metastable state are therefore termed *forbidden lines*. But at the extremely low densities prevailing in the gaseous nebulae, atomic collisions are very infrequent, occurring for a given atom at average intervals of several hours or days. Under these conditions, the forbidden lines can appear. Under

these same conditions, moreover, the normal permitted lines do not in general appear, because the electrons are moving too slowly to excite the atoms to the normal levels, which correspond to higher energy than the metastable levels. Thus the spectra of the gaseous nebulae are dominated by forbidden lines. In this way Bowen was able to account for their spectra and, by the investigation of possible electronic configurations, to identify all the principal lines. The two strong green (nebulium) lines were proved to be due to doubly ionized atoms of oxygen; other lines were due to atoms of oxygen, nitrogen, neon, and sulphur in various stages of ionization.

Forbidden lines of various elements are observed in the later stages of the eruption of a nova. When the outburst of a nova occurs, the star throws off one or more shells of gas. As such a shell of gas moves outwards from the star, the radiation of the star available for exciting the atoms in the shell becomes progressively diluted, whilst the density of the gas in the shell diminishes; thus the metastable levels tend to become populated while the normal levels become depopulated. Forbidden lines therefore appear in the spectrum. Early in the post-maximum stage of the slow nova, Nova Pictoris (1925), forbidden lines of ionized iron [FeII][1] became a prominent feature of the spectrum. These [FeII] lines are prominent also in the spectrum of the variable star, Eta Carinae, and other 'iron' stars. The spectrum of Nova Pictoris for some years after its outburst was studied by the writer. Many lines appeared in the spectrum at various stages, for which no origin could at the time be assigned. Prominent amongst them was a very strong line at 6086A, which at one stage was the strongest line in the spectrum and which had never previously been observed in any celestial spectrum. It was subsequently identified from theoretical considerations by Bowen and Edlén as an [FeVII] line, whilst other lines in the spectrum were due to both [FeVII] and [FeVI]. Swings and Struve have since shown that lines which had appeared in the spectrum in earlier stages were due to [FeIII], [FeIV] and [FeV]. Thus all the stages of ionization from [FeII] to [FeVII] were represented in succession. Lines of [FeV], [FeVI] and [FeVII] have been found to be prominent also in the present spectrum of the slow nova RT Serpentis (1909). The forbidden spectra of iron are becoming of increasing importance for the discussion of high-excitation atmospheres of stars and of novae.

The successful identification of lines found in various celestial spectra as forbidden lines arising from transitions from metastable states of the commoner atoms encouraged the hope that the coronal lines might prove to be of a similar nature. But their identification proved much more intractable and remained for many years the outstanding problem in stellar spectroscopy. Some twenty-three lines in all have been observed in the spectrum of the corona, not a single one of which had ever been observed in any other celestial spectrum until 1942, when certain of them were detected in the spectrum of the nova-like variable star RS Ophiuchi. The problem has at length been solved by the Swedish physicist, Edlén.

The starting-point of the investigation was the recognition that the term separations of certain configurations of FeX and FeXI atoms coincided with the wave numbers of two of the coronal lines. Permitted lines of the spectra of these highly ionized atoms were observed by Edlén in the extreme ultra-violet under very high excitation by high-voltage sparks. It was also noticed that the analogous term separations of certain configurations of CaXII and CaXIII atoms coincided with the wave numbers of two fainter coronal lines. Assuming the identifications of these four lines to be correct, Edlén was able, by extrapolations based on iso-electronic sequences, to carry out in a consistent manner an almost complete identification of the coronal spectrum; there remain only a few faint lines for which identifications have not yet been found. The identified lines, which are all forbidden transitions, belong to the spectra of FeX, FeXI, FeXIII, FeXIV, FeXV; NiXII, NiXIII, NiXV, NiXVI; CaXII, CaXIII, CaXV; AX and AXIV. The strongest lines are due to iron atoms, from which nine, ten, twelve and thirteen electrons have been stripped; the nickel analogues of all these iron atoms appear in the spectrum with intensities of about one-tenth those of the iron lines. FeXII and NiXIV atoms are no doubt abundant in the corona, but there are no lines in the spectra of these atoms in the observable region.

Many other elements, such as Si, Mg, C, N, O, and Ne, which are cosmically abundant, would not be expected to show in the corona, because at the appropriate ionization level their spectra

[1]Forbidden lines are usually denoted by brackets. FeI denotes the spectrum of neutral atoms of iron; FeII, FeIII . . . the spectra of atoms that have been stripped of one, two, . . . electrons.

either do not contain forbidden lines or such lines fall outside the observable region. Lines of K, Cr, Mn, and Co might be expected to appear faintly, but have not been detected. Lines of H and HeII might be present, but the great strength of these lines in the solar chromosphere and prominences would conceal fainter coronal lines.

These identifications are of the greatest importance for stellar physics and will undoubtedly inspire many theoretical investigations. They suggest electron temperatures of the order of 200,000° to 400,000° C. This accords with the temperature of 350,000° C, which, according to Grotrian, corresponds in thermal equilibrium to the mean velocity of the scattering electrons in the inner corona. The small density gradient and high turbulence observed in the corona are physical factors probably associated with the very high degree of excitation. Many solar effects are now recognized to require much more energy in the far ultra-violet than is emitted by a black-body of the sun's size at a temperature of 6,000° C. The source of the extremely high excitation prevailing in the corona remains at present obscure; much work will be needed before a full understanding of the conditions in the corona is obtained.

The matter of lowest density known to the astronomer is the diffuse interstellar gas, whose density is of the order of 10^{-24}. This density is far lower than that of the gaseous nebulae; a sphere of 1,000 miles radius contains about enough matter to make a small marble. In 1904 Hartmann observed in the spectrum of the binary star Delta Orionis two lines, in the position of the H and K lines of calcium, which were much sharper and narrower than the normal lines of the star, and which remained stationary whilst the other lines in the spectrum varied in position with the orbital motion of the star. It was suggested by Eddington that these lines originated in absorption by atoms of calcium in interstellar space. Some years later Miss Heger and Wright, at the Lick Observatory, found that the yellow D lines of sodium and a pair of sodium lines in the ultra-violet near 3300A showed a similar behaviour. In recent years a number of additional sharp and narrow interstellar lines, mostly in the violet and ultra-violet, were found by Dunham and Adams, using a powerful high dispersion spectrograph, whilst six broad and diffuse lines, of interstellar origin though of quite a different character from the normal lines, were found in the red and orange by Merrill and Wilson. Because of the low density in interstellar space and the dilution of the stellar radiation, the only atomic lines to be expected are those arising from the lowest energy levels or ground states of the neutral or ionized atoms. Though ionization takes place at a very slow rate, an atom, when once ionized, will remain in that state for a long time, because its encounters with free electrons will be very infrequent. Interstellar lines of neutral atoms of sodium, calcium, potassium, and iron, and of ionized atoms of calcium and titanium, have been identified. It was clear that several other lines could not be due to transitions in atoms. It was suggested by Swings and Rosenfeld that they might be of molecular origin. Molecules in interstellar space would be expected to be in the lowest rotational level of the zero vibrational level of the ground electronic state. By investigating commonly occurring diatomic molecules, it was proved that the remaining sharp lines were due to neutral molecules of CN and to neutral and ionized molecules of CH, giving the first direct evidence of compound molecules in interstellar space. The origin of the broad diffuse interstellar lines is still unknown.

The majority of interstellar atoms evade discovery because the lines arising from transitions from their ground levels are in the far ultra-violet, in the region to which the earth's atmosphere is opaque. Thus though hydrogen must be the most abundant element in interstellar space, interstellar dark lines of hydrogen have never been observed. Recently, however, with the aid of a specially designed spectrograph, Struve and Elvey have been able to detect faint emission lines of hydrogen and ionized oxygen, caused by the downward cascading of electrons captured by ionized atoms. This faint glow of light is found only in regions of the Milky Way.

The spectra of comets have provided some interesting problems of identification and interpretation. The presence of molecules of C_2, CN, CH, and of ionized molecules of CO and N_2, was established some years ago. Within the last three years, molecules of OH, NH, and ionized CH have been shown to be present. A group of strong lines near 4050A has proved difficult to identify. From the sharpness of the lines, Swings inferred that the responsible molecule must be a hydride, and at first suggested ionized NH, because all other diatomic hydrides of the light elements were accounted for; but Hertzberg pointed out that the distribution of the intensities among the component lines was unlikely for a diatomic molecule. Swings has now proved conclusively that

the lines are produced by the triatomic molecules CH_2. This is an outstanding achievement, and forms the first evidence for triatomic molecules in astronomical spectra. The lines have not yet been produced in the laboratory. Another strong group near 6300A is almost certainly due to a dissociation product of ammonia, viz. NH_2. It may also be mentioned that besides the Swan bands of $C^{12}C^{12}$, some comets have also revealed $C^{12}C^{13}$, the only isotopic molecule detected in comets.

Though most of these radicals are not chemically stable, they can be found in low temperature sources, like a cometary atmosphere or the interstellar gas, because of the low density and consequent almost complete absence of collisions. They are physically stable, because their ground electronic state has an energy smaller than the energy of the separated atoms. The problems of molecular formation, dissociation, and ionization are quite different in comets and in the interstellar gas. In the latter, two-body encounters with simultaneous emission of radiation provide the main source of molecular formation. In comets, the atmosphere is generated by the liberation of gases occluded in the meteorites forming the head; these saturated parent molecules are broken up by photodissociation, followed by ionization. Differences between band structure observed in comets and in the laboratory have been explained by a resonance-fluorescence mechanism, strong Fraunhofer absorption lines at critical wavelengths materially influencing the band structure.

In celestial spectra, the most important features that have not yet been identified are the broad emission bands of supernovae. These extraordinary stars at their maximum brightness surpass the luminosity of the sun by a factor of 10^8, and in the course of their outburst radiate in a few months as much energy as the sun radiates in some 50 million years. Their spectra, which are radically different from any other celestial spectra, are characterized by extremely broad and partially overlapping emission bands, with large and variable red shifts. The widths of the bands at maximum brightness are about 400A, but settle down to about 100A within a few weeks after maximum. Practically no continuous spectrum is shown. The changes in structure and relative intensity, the overlapping, and the variable displacements, make identification extraordinarily difficult. The weakness or absence of bands due to hydrogen or helium indicates a very high degree of ionization. Some of the changes that occur suggest considerable changes in ionization level. No identifications can be proposed at present without reservation. In our own galaxy, outbursts of supernovae occurred in A.D.1054 (recorded in Chinese annals), and in 1572 and 1604 (observed by Tycho Brahe, Kepler, and others).

Book reviews

MEASUREMENT OF FINE PARTICLES

Determination of Particle Size in Subsieve Range. Report of Discussions. *Pp.* 69. *British Colliery Owners' Research Association and the British Coal Utilization Research Association, London.* 1944. *N. p.*

In the work of the two associations under whose auspices the two conferences here reported were held in June 1941 and July 1942, as also in the study of many industrial processes, accurate measurement of the sizes of fine particles is a matter of great urgency. It is evident from this interesting and useful report that, although apparatus and methods now in use are very satisfactory for comparison of fineness, much remains to be done, e.g. in the determination of absolute size distribution and in the effective dispersing of a powder in a liquid.

In the first half of the booklet we have a paper by two members of each association on a joint study, resulting from the first conference, of the sedimentation and light-extinction methods for particle diameters down to about 25μ, and microscope methods for heterogeneous powders. The presentation of the paper at the second conference was followed by a discussion by many investigators, whose contributions form the latter part of the report.

W. JEVONS

CONCEPTIONS OF VALENCY

Valency: Classical and Modern, *by W. G. Palmer. Pp.* x + 242. *University Press, Cambridge.* 1944. 10*s.* 6*d. net.*

An understanding of the ways in which atoms are linked together and of the factors which determine the properties of their compounds is indispensable to any serious student of modern inorganic chemistry. In this book, Dr Palmer has presented the development of the conception of chemical valency, from the earliest theories of the nineteenth century to the most modern aspects of the electronic theory, in a succinct and readable form, and against the solid background of the experimental facts of pure chemistry. The first part of the book is quite suitable for the general reader, while the later chapters include, among other topics, recent developments of the electronic spin theory and its spectroscopic basis, the method of molecular orbits, bond energies, and applications to organic chemistry.

The book contains a surprisingly large amount of matter for its size. In addition to the exposition of the theories of valency, it contains much quantitative information relating to the

structure of gaseous and solid compounds, obtained from electron-diffraction, X-ray, and spectroscopic measurements. References to original papers are plentiful. F. FAIRBROTHER

THE DEVELOPMENT OF COMPARATIVE ANATOMY

A History of Comparative Anatomy from Aristotle to the Eighteenth Century, *by F. J. Cole. Pp. viii* + 524, *with frontispiece and* 200 *text figures. Macmillan & Company, Limited, London.* 1944. 30*s. net.*

Professor Cole is the recognized interpreter of the history of zoology. His long awaited work bears no sign of these difficult times. It is a model of patient research and attractive exposition.

What is comparative anatomy? Its father, Aristotle, saw that different types of animals fall into a relatively few groups each of which accords to a certain pattern. Some of these groups nearly correspond to the 'Classes,' 'Orders,' and other higher divisions of modern zoology. He also recognized that animals breed only with forms that closely resemble themselves and always breed their own like. Such a form (*eidos*) we now call a 'Species.' Aristotle thus provided the basis for a classification. By the seventeenth century it was realized that a better guide to grouping than superficial appearances was inner structure. For its study the term 'comparative anatomy' was introduced. With its earlier exponents, such as the Belgian Vesalius (1514–64) and the Frenchman Belon (1517–64), the comparison was always, as Professor Cole shows, with human anatomy. Not until the last years of the sixteenth century was any animal studied for its own sake. Professor Cole shows further that the study came to flower with development of a special craftsmanship in the seventeenth century, a period to which about two-thirds of his work is devoted.

Of that century, he describes three great schools. The English school was centred round the Royal Society of London. Among its stars were Harvey (1578–1657), discoverer of the circulation of the blood; Hooke (1635–1703), first writer on microscopy and among the most universal of scientific geniuses; and John Ray (1627–1705), perhaps the greatest naturalist of the century and one of the greatest of all time. The Dutch school produced two unique figures. Leeuwenhoek (1632–1723), greatest of microscopists, had no scientific training and no language but Dutch. His researches were published by our Royal Society. He made his own microscopes, which contained only one lens. With them his dexterity was marvellous. Notably he was the first to see bacteria. Swammerdam (1637–80) graduated as a physician at 30. His remaining thirteen unhappy years were shortened to less than eight effective ones by mental disturbance. Yet he performed prodigies of research; they were put together long after his death in a volume which contains the finest series of microscopic observations between two covers. The French school is personified by the brilliantly versatile Claude Perrault (1613–88), who did more for comparative anatomy than any of his time. He studied medicine at Paris but abandoned it for architecture, in which he attained the highest eminence. His façade of the Louvre (1666) was the *chef d'œuvre* of French architecture. His interest in comparative anatomy grew from about 1667, and his mechanistic attitude to animal structure is an expression of his architectural and engineering bias.

Throughout the book Professor Cole economizes space by avoiding familiar material. Thus hardly any of his many figures have appeared in a modern book. We also draw attention to the unusual skill of the bibliography and indices. CHARLES SINGER

RELATION OF ART AND SCIENCE

Art and Scientific Thought, *by M. Johnson. Pp. viii* + 192. *Faber & Faber, Limited, London.* 1944. 16*s. net.*

Walter de la Mare says in his Introduction, 'Nowadays there is little excuse for staying ignorant.' The average reader will certainly take this dictum to heart when he tries to remember whether Beethoven's Quartet, *Opus* 130 in B-flat, with the fugal ending, now called *Opus* 135, comes before or after *Opus* 132 in A minor; or whether it was Al-Khujandi who obtained the inclination of the ecliptic as 23° 32′ 21″ and Al-Battani as 23° 35′ or the other way about. These examples refute the publishers' claim that the book may be read without previous acquaintance of any of the artistic or scientific techniques mentioned in it. Dr Martin Johnson produces, however, a very stimulating series of monographs on such widely divergent subjects as Chinese jades, the ballet Petrouschka, Baghdad mathematicians, Chinese astronomical instruments, and so on. These essays are very able and readable, but the book on the whole lacks coherence, and one has the feeling that the title was chosen to cover a widely differing set of articles, rather than that the articles were written to illustrate a definite line of thought.

The author seems obsessed by the idea of a serious conflict between science and the arts. There certainly was one during the industrial heyday of last century, but to my mind there is no conflict now: there is only a misunderstanding due to the fact that the artist's pattern, to use the author's phrase, is interpretable in different ways according to the observer. This dualism can surely be explained historically by the gradual evolution and perfecting of any science, while the arts show peaks of perfection followed by abysmal declines.

It would have been interesting to hear the author's views on post-war problems, when the sciences leave their lethal pursuits and play, we hope, an integral part in a saner world.

ERIC KNIGHT

INTERNATIONAL NOMENCLATURE OF DISEASES

Polyglot Glossary of Communicable Diseases, *by Yves Biraud.* (*Reprinted from the Bulletin of the Health Organization. Volume X, No.* 3, *pp.* 202–556.) *Allen & Unwin* (*League of Nations Publications Department*), *London.* 1944. 4*s.*

The translation of literature, where language is the expression of the emotional experience of a people, in varying shades of style, is at best a makeshift, a problem with an unlimited number of solutions equally valid—or invalid. Scientific concepts, however, being amenable to unequivocal definition, one way or another, have their precise equivalents in most civilized languages. Nevertheless, a translator is often baffled by 'false friends,' words nearly identical in two or more languages, but applied with different meanings. In the medical sciences, where no uniform Latin nomenclature exists and the looseness of common parlance adds to the confusion, failure to note a false friend may even have fatal consequences where international co-operation is involved; and the establishment, through the Health Organization of the League of Nations, of an international nomenclature of diseases, is obviously of paramount importance. The work under

review is based mainly on reports received from all countries in preparation for the Fifth International Conference, in 1938, by the Service of Epidemiological Intelligence and Public Health Statistics and by the Library of the League. The arrangement and indexing of the material are skilfully done, and Part I gives a clear and concise guide to the use of the tables. Part II contains, in the first column, the international designations of 161 groups of diseases with their subdivisions, all numbered, and in subsequent columns the corresponding names in Latin and in 23 European languages. The index, Part III, is a list of all the names used, arranged alphabetically irrespective of language, with the corresponding classification number and an abbreviated indication of the language (in French). A translation of Cyrillic characters is included.

In a work of this order, perfection is a matter of successive approximation. It is to be hoped that the invitation to readers to collaborate in filling up inevitable gaps will meet with ready response. J. A. WILCKEN

PLASTICS IN USE

Plastics for Production, *by Paul I. Smith. Pp. viii + 180. Chapman & Hall, Limited, London.* 1944. 12*s.* 6d. *net.*

The author explains in his preface that the title was chosen in preference to 'The Properties of Plastics' because he aimed at 'an interpretation rather than a mere description of properties.' The importance of interpreting the properties of a bewildering variety of plastics to a growing user-public cannot be exaggerated. The lay-out of the book, with only two chapters devoted to properties and the remaining eight to different aspects of plastics in use, is in keeping with the aim. It is, however, a very difficult task, requiring a higher level of critical appreciation than is maintained throughout this book.

The author has shown restraint in avoiding any reference to the chemistry of plastics. This deliberate omission has led him astray at times, notably in his classification, which includes only polyisobutylene under 'Hydrocarbon Plastics,' giving polythene a separate heading, while such dissimilar products as polyvinyl chloride, acetal, butyral, and polyvinylidene chloride are included under the single heading of 'Vinyl Resins.' In the same chapter the sections on new applications require revision and amplification; some of the applications are not new, others are trivial, others of great importance are dismissed in a sentence.

The chapter on 'Plastics for Insulation' leaves the impression that polystyrene is the principal high-frequency insulator of today, whereas Britain was the first country to rely almost entirely on polythene, which is now also being made in America.

Despite its faults, this little book will be useful to recruits to the industry, who want a bird's-eye view of plastics in use. A. CARESS

BEAUTY AND DESIGN IN SHORE ANIMALS

Seashore Life and Pattern, *by T. A. Stephenson. Pp.* 28, *with* 16 *plates.* (*A King Penguin.*) *Penguin Books, Limited, Harmondsworth and New York.* 1944. 2*s. net.*

During the Victorian era a widespread interest in the life of our shores was kindled and sustained by the popular and beautifully illustrated books of Edward Forbes, P. H. Gosse, the Sowerbys and many others. More recently this interest has been largely confined to the scientific naturalist, and the extensive literature has appealed more to the mind than the eye. Professor Stephenson is one of the few modern marine biologists who are also artists. His volumes on Sea Anemones published by the Ray Society contain probably the finest modern coloured plates of marine animals. In the small volume under review he has sought to arrest the eye of the common reader by the revelation, in many coloured plates, of the beauty of a diversity of shore animals, but also, both there and in a series of black and white figures, to emphasize the significance of design and pattern. He shows how this is based on both explicit and implicit lines, and indicates how mathematical relations lie at the base of the sensation of beauty which these creatures arouse within us. With the aid of diagrams he analyses the nature of the intrinsic patterns in selected examples. This is an unusually delightful book. It should arouse wide interest and give pleasure to many; best of all it may lead the author to develop this tantalizingly slender essay into the larger work of which he is so supremely capable. C. M. YONGE.

FRANKLIN, HENRY, EDISON, GIBBS

Famous American Men of Science, *by J. G. Crowther. Volume I, pp.* 191 *and Volume II, pp.* 159. (*Pelican Books.*) *Penguin Books, Limited, Harmondsworth and New York.* 1944. 9*d. net each volume.*

Mr Crowther's well-known book on famous American scientists (Franklin, Henry, Edison, Gibbs) first appeared in 1937; the biographies of Franklin and Henry now form the first volume of a Pelican reprint, and those of Edison and Gibbs the second volume. Although the reviewer holds that the Marxist view that the progress of science is conditioned by social and economic needs is incomplete and neglects other factors, he has re-read these studies with no less interest than on their first appearance seven years ago; for they are characterized throughout by sound scholarship and careful analysis, and the author everywhere succeeds in making his subjects live before the reader's eyes.

Franklin is perhaps the ideal subject for a biographer—Franklin, pioneer in electricity, founder of the physics and chemistry of surfaces, statesman, economist, ambassador, the visionary who foresaw an empire of British commonwealths, a League of Nations, and the possibilities of what are now called 'paratroops,' a Renaissance figure strayed into the eighteenth century and for a part of it 'the world's intellectual exchange.'

Joseph Henry is in some ways a more difficult subject; but Mr Crowther presents a sympathetic study of his great contributions to electricity and his remarkable administration of the Smithsonian Institution. The comparison between Faraday's and Henry's achievements is very fairly and competently done.

Edison is well presented with adequate detail. If this remarkable man really possessed those rare qualities that are commonly summed up in the word 'genius,' Mr Crowther's study of his achievements shows clearly that, by lack of scientific training, those qualities were sometimes woefully wasted.

Willard Gibbs must always be an interesting study; and Mr Crowther has thoroughly appreciated the intellectual grandeur of the founder of generalized thermodynamics and chemical energetics, one of the greatest minds since Newton. This, in one reader's opinion, is the most attractive of these four 'lives.' D. MCKIE

Notes on contributors

W. E. S. TURNER,

O.B.E., D.Sc. (London), M.Sc. (Birmingham), F. Inst.P., F.S.G.T., F.R.S.,

Was born in 1881. After attending King Edward VI School at Birmingham, he proceeded to the University of Birmingham, where he was elected University Research Scholar in Chemistry and Ehrhardt Research Prizeman. He became Lecturer in Physical Chemistry at the University of Sheffield in 1904, and organizer of the Department of Glass Technology at that university in 1915. Since 1920 he has been Professor of Glass Technology at the university. He is a member of many British and foreign societies concerned with the technology of glass, and was President of the Society of Glass Technology and of the International Commission for Glass Technology. He has published some hundreds of scientific papers dealing with physical chemistry and the technology of glass, and is Editor of the *Journal of the Society of Glass Technology* and of the *Glass Review*. His recreations include walking, mountaineering and travel.

ALLAN FERGUSON,

M.A., D.Sc.,

is a Lancastrian, having been born at the moorland village of Entwistle, near Bolton-le-Moors, in 1880. He was educated at the Harris Institute, Preston, and the University College of North Wales, Bangor. At an early stage of his career he deserted pharmacy for physics, and is now Assistant Professor of Physics at Queen Mary College in the University of London. He is one of the general secretaries of the British Association for the Advancement of Science, a past president of the Physical Society, and one of the editors of the *Philosophical Magazine*. He has written many papers on capillarity, on the determination of specific heats, and on other physical subjects. A collector of editions of Horace, Johnsoniana, and contemporary reports of trials, he is interested in dialects, likes gardens (but dislikes gardening), and is not a golfer.

KENNETH M. SMITH,

Ph.D. (Cantab.), D.Sc. (Manchester), F.R.S.,

Was educated at Dulwich College and at the Royal College of Science, London. During the war of 1914–18 he served in France. In 1920 he was appointed Senior Lecturer in Agricultural Entomology at the University of Manchester, and held the post of Advisory Officer to the Province. Six years later he became Senior Research Assistant at the Potato Virus (now the Plant Virus) Research Station of the School of Agriculture at Cambridge. In 1939 he succeeded Dr R. N. Salaman as Director of the Station. Most of his scientific work has been on plant viruses, on which he has written many articles and books; among the latter are two which have had much success as popular expositions of our scientific knowledge of viruses. He was formerly fond of cross-country running, but now devotes his spare time and energy to gardening.

A. M. TYNDALL,

D.Sc. (London and Bristol), F.R.S.

Born in 1881, he was educated at University College, Bristol, where he was Lecturer in Physics when the University of Bristol was founded in 1909. He succeeded to the Henry Overton Wills Chair of Physics there in 1919, and played a leading part in the inception, and completion in 1927, of the Henry Herbert Wills Physical Laboratory, a new and important centre of research and teaching erected through the generosity of the son of Henry Overton Wills. This laboratory subsequently received endowment, through the University, from the donor on his death, from the memorial gift of a second chair (now held by Professor N. F. Mott) by his surviving brother Melville Wills, and from the Rockefeller Foundation. Professor Tyndall is director of this laboratory, but the subject of his article is only one of the many fields of inquiry which engaged members of his staff before the war. A number of workers both in Britain and abroad will have pleasant memories of several international conferences held in the Wills laboratory.

Professor Tyndall has served on the governing body of various societies and institutions, including the Royal Society, the Physical Society, the Royal Institution, and the National Physical Laboratory. He has also made visits to many universities in foreign countries and the Dominions.

Sir HAROLD SPENCER JONES,

M.A., Sc.D., B.Sc., F.R.A.S., F.R.S.,

Has held the position of Astronomer Royal since the year 1933. He was born in London in 1890 and was educated at Latymer Upper School, Hammersmith, and Jesus College, Cambridge, where he had a brilliant academic career. From 1913–23 he was Chief Assistant at the Royal Observatory at Greenwich, and from 1923–33 held the post of His Majesty's Astronomer at the Cape of Good Hope. He is known throughout the world not only for his distinguished original contributions to astronomy but for his skill in explaining to laymen the most abstruse astronomical and cosmological conceptions and theories. He was knighted in 1943, and in the same year was awarded the Royal Medal of the Royal Society and the Gold Medal of the Royal Astronomical Society. He is a past president of the latter Society and of the British Astronomical Association, and was vice-president of the International Astronomical Union from 1935 to 1938. President of the British Horological Institute, he is also a Foreign Associate of the National Academy of Sciences (U.S.A.), and an Honorary Member of many Dominion and foreign astronomical societies. His interests include pictures, books (particularly limited editions and special presses), and music.

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